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Biological and Economic Analysis of Lobster Fishery Policy in Maine

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BIOLOGICAL AND ECONOMIC ANALYSIS
OF LOBSTER FISHERY POLICY IN MAINE

submitted to the

Committee on Marine Resources
State of Maine, 112th Legislature

by

L.W. Botsford and Associates

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February 15, 1986

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Foreword

This document provides an evaluation of several policy options pertinent to the Maine lobster fishery. The principal options examined include an increase in the lower gauge, removal of the upper gauge, and dependence on existing (or stepped-up) V-notching programs. Our original tasks, as set out by the Committee on Marine Resources, were: i) to provide a thorough review of the state of knowledge of lobster biology and markets; and ii) to provide an evaluation of the impacts of proposed policies. Our summary of the state of knowledge is provided in the main body of this document, supplemented by more extensive reviews of particular studies in Appendix 1. We have attempted insofar as possible to make these reviews accessible to the layman who is not an expert on fisheries biology or economics. Since both metric and English measurement units are typically used in scientific lobster research, both appear herein. We present all essential results in English units, however, and have included a chart for converting between millimeters and inches, pounds and grams, and lobster length to lobster weight in Appendix 2.

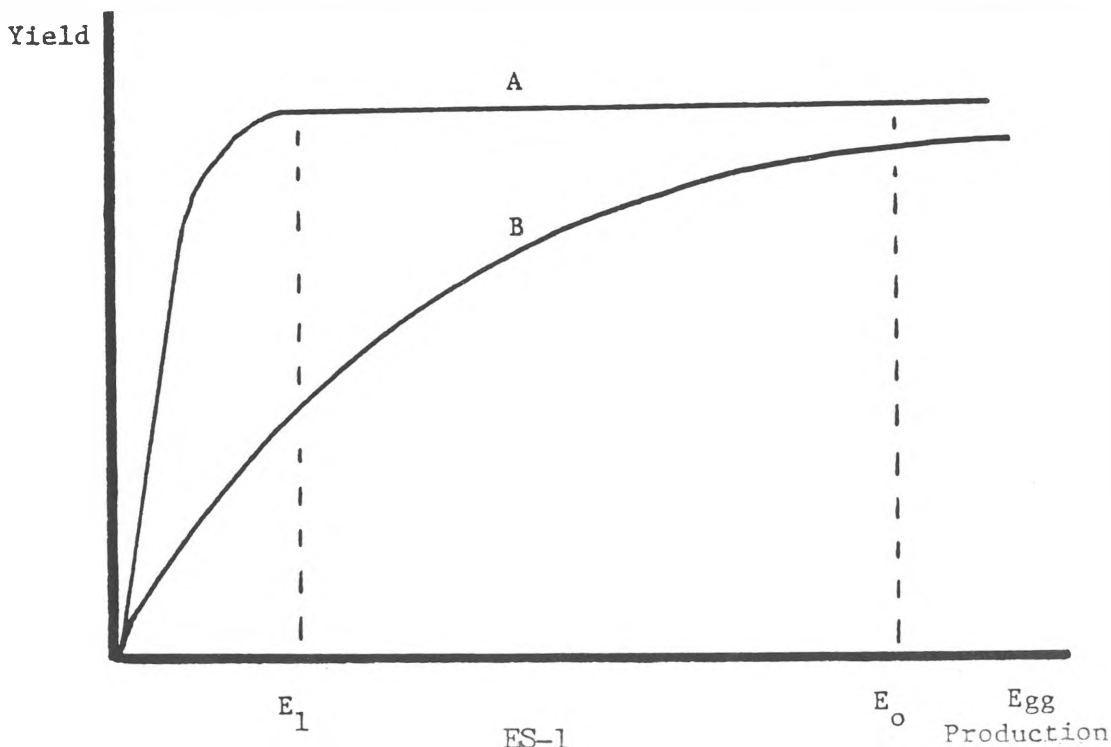
The task of assessing the pros and cons of various options has proven to be the more difficult of our originally-specified responsibilities. We have gone beyond the original scope of the proposed work in several ways. First, we have undertaken the development of a detailed computer model which utilizes Maine-specific data to analyze Maine-specific policy options such as V-notching. This is the first time this has been done on this scale. Second, we have gone to considerable lengths to explain the implications of both our knowledge and our uncertainty about lobster biology and economics. Throughout we have tried to remain as objective and neutral as possible in evaluating options, a task actually not as difficult as it may seem since we have the benefit (as "outsiders") of having no "axe to grind" or favored policy. One important conclusion that has come out of our study, however, is that there is perhaps more need to educate participants involved in lobster policy disputes about the implications of what we know (or do not know) than there is to add to our basic knowledge. Lobster population biology is complicated and there are several important misconceptions and misinterpretations of "facts" which stand in the way of resolving current debates. We hope that this report is taken as it is intended, namely, as an informative guide to the issues underlying current policy discussions rather than as a recommendation for specific policy options. It is also our hope that this study may serve as a starting point for forging consensus over future directions and moving away from the largely antagonistic atmosphere which exists at present.

EXECUTIVE SUMMARY

Although there is widespread agreement with the goal of maintaining a high level of productivity in the Maine lobster fishery, there is less agreement between managers, lobstermen, dealers, and researchers as to how to ensure it. Controversies over the status of the stocks and what (if anything) needs to be done about it have persisted for the nearly ninety years that lobster fishing has been managed in Maine. Such conflict is not unusual, however, and appears in most open access fisheries where managers (who are charged with stewardship of the resource) must constrain the activities of increasing numbers of fishermen who are competing for a fixed common property resource. Unfortunately, it is also apparent that the conflicts that now characterize the Maine lobster fishery are inevitably bound to escalate in the future as more effort is drawn into the fishery. The purpose of this report is to assess the validity of various issues raised in these policy debates and to provide some steps toward resolution of existing conflict.

Of the many potential impacts of management actions, two stand out as most important to both managers and lobstermen; total catch (or value of catch) and stock safety. Whereas total catch is readily observable and measurable, stock safety is particularly difficult to assess or even define in practical terms. We do know that as fishing effort increases, fewer eggs will be produced by the population unless other measures are taken simultaneously. The effect of reduced egg production on subsequent recruitment (number of young entering the fishery) is not well understood, however. Two possibilities present themselves as shown in Figure ES-1 below.

Figure ES-1: Hypothetical Egg Production/Recruitment Relationships.



One possibility (labelled Curve B) is that there is warning when egg production begins to fall below viable levels because recruitment and hence yield begins to fall. It is important to note, however, that even in this case, the response to reduced egg production will not be felt in the fishery for the 5-7 years that it takes recruits to mature from eggs. The other possibility (and the one most fisheries biologists believe) is that the relationship is more like curve A. If this is the case, the fishery can reduce egg production substantially without any measureable effects on yield over a large range. At some point, however (labelled E_1), further decreases in egg production will cause a sudden and drastic fishery collapse.

Unfortunately, it is not known which of these relationships applies to the Maine lobster fishery, nor do we know whether egg production currently is relatively "safe" (E_0) or close to a threshold (E_1). We do know that fishing effort has increased substantially over the past two decades and that inshore egg production must have been reduced, other things equal. Recruitment to the inshore stocks may be coming from offshore stocks and there may be some recruitment provided by programs such as the V-notching program. Whether either of these is true, however, is unknown at present. What is clear is that if measures are undertaken to increase egg production, the stock will be more "safe" than at present. In the analysis that follows, therefore, we present projections of management policies both in terms of yield and total system egg production.

The ultimate confidence that we can place in our projected results of various management options depends on the knowledge used to make the projections. Population dynamics of the Maine lobster stocks are not completely understood, but we know more about some aspects than others. With regard to individual lobsters, we know that when they enter the fishery they are molting once a year and the increase in carapace length is approximately 14 percent. Molting frequency declines with age, and mature females generally molt every other year. We also know quite a bit about reproduction. We know the size at which lobsters mature (50 percent are mature at 4 inches), how many eggs they produce at each size (this increases as they grow larger), and how often they bear eggs (generally every other year). We know that the mortality rate due to fishing is quite high (about 90 percent is removed each year), but we have a very poor idea of the natural mortality rate of those that survive the fishery (we think it is between 5 percent and 25 percent per year). Another facet of behavior about which we know little is offshore migration. Most mature lobsters appear to undergo a seasonal offshore migration of 20 or so miles, but some mature lobsters migrate a longer distance on a more permanent basis. The fraction of large lobster moving permanently has been measured to be 10 to 15 percent.

Overall, even though some of the parameters are not known exactly, we have a good idea of how the fishery functions. Because of a sampling program instituted by the Maine Department of Marine Resources (DMR), we have a good record of catch and the distribution of lobster sizes in the fishery. Most of the catch each year are lobsters that have just molted into the fishable size range (i.e. they are between 3 and 3/16 inches and 3 and 9/16 inches). More than 90 percent of these are removed by fishing or

natural causes in the first year in the fishery and each year thereafter, except when they are either berried or V-notched. This results in a "stair step" pattern of abundance by size class. Due to the high combined mortality rates, only a small fraction survives to become sexually mature, and even fewer reach the upper limit of 5 inches.

An important aspect of the fishery that is not well understood is the impact of the V-notching program. DMR V-notches about 10,000 lobsters each year and the fishermen V-notch an unknown number of lobsters each year. The total number of V-notched lobsters in the population and the effects of the process of V-notching on reproduction and mortality are unknown, however. (There has been one attempt to measure the number of V-notched lobsters in the population, but more effort in this area is needed).

Economic aspects of the lobster fishery and markets are reasonably well understood. The market is supply driven, and total supply varies unpredictably from year to year by about plus or minus 10 to 20 percent. There is also a seasonal variation in supply which is partially smoothed by Canadian imports and pound supplies. Price is relatively unresponsive over the ranges for which we have data. Thus, we can be reasonably sure that an increase in catch will lead to an increase in revenues and a decrease will lead to a fall in revenues.

Based on all of the above outlined knowledge of lobster biology and markets, we have constructed a computer model of the fishery, and used it along with other information, to evaluate various policy options. In addition to projecting the impacts on future catch and egg production, we have also evaluated the effects of our less certain knowledge of various aspects of the population and fishery dynamics. Thus, we not only project the results of the options, but also suggest the confidence that can be placed in our projections.

The first option available is to do nothing and continue with the status quo. It is fairly certain that as real prices rise (due to population and income growth) more effort will be attracted into the fishery, hence egg production will decline. What is not known is whether the egg production/recruitment relationship is a "threshold" type and, if so, how close we are now to the threshold. If no counteracting measures are taken and the exploitation rate continues to increase, the fishery will decline at some point, however.

The first "active" option is to increase the lower gauge. This would lead to an initial short term decline in catch followed by a gradual increase to a higher long-term average catch after about 4 or 5 years. The initial decline varies with the amount by which the gauge is increased, roughly 8 percent for each 1/16 of an inch. Gradual changes in smaller increments would diminish the first year impacts proportionately but increase the time to reach the long term yield. The final long-term yield also varies with the size of the change; each 1/16 inch gauge increase will lead to approximately a 2.6 percent increase in yield. (See Table ES-1) An increase in the lower gauge also increase egg production. For example, an increase of 1/16 inch will increase egg production by about 30% over the baseline case.

Table E1: Summary of the Impact of Management Options.

	Catch (millions of pounds)	Egg Production (billions)
<u>Baseline</u>		
l.g. = 3 3/16"		
u.g. = 5"	22.46	5.5
berried protection no V-notching		
<u>Gauge Increase</u>		
l.g. = 3 1/4"	23.04 (+2.6%)	7.0 (+27%)
l.g. = 3 5/16"	23.68 (+5.4%)	9.3 (+69%)
<u>No Upper Gauge</u>	22.51 (+0.2%)	3.8 (-31%)
<u>V-Notching</u>		
(percent of trapped berried females notched)		
10 percent	22.44 (-0.1%)	9.0 (+64%)
25 percent	22.39 (-0.3%)	13.4 (+144%)
50 percent	22.33 (-0.6%)	18.8 (+242%)
100 percent	22.26 (-0.9%)	25.2 (+358%)

These projections are sensitive to our estimates of mortality and growth rates. If natural mortality rate is as high as 30 percent per year, there would be no long term gain from a gauge increase. The initial decline following a gauge increase is sensitive to our measurements but we can be reasonably sure that it will be about 8 percent for a 1/16 inch increase made all at once (rather than incrementally). The gauge increase results do not appear to be sensitive to measured levels of offshore migration.

Another option is removal of the upper gauge measure of 5 inches. We found that in spite of the fact that very few individuals reach that size, it does provide some potential protection of broodstock. Our model projects that removal of the upper gauge would decrease egg production to about 70 percent of its former value with a very small effect on long term yield. These projections assume that the prohibitions on landing lobsters over 5"

are actually effective in keeping fishermen from retaining trapped oversize lobsters. Most anecdotal evidence suggests, however, that the prohibition on landing lobsters over 5" simply imposes an extra cost on lobstermen and that these lobsters are sold outside of Maine or unrecorded. If this is the case, then our projected benefits of leaving the maximum gauge in force are overstated and may even be overshadowed by the extra costs imposed and by the loss of valuable data.

Another important option is to depend on the V-notching program for stock safety through egg production by V-notched lobsters. Our model results show that V-notching has the potential to contribute substantially to egg production. (See Table ES-1) For example, if 10 percent of all trapped females that were bearing eggs were V-notched, egg production would be equivalent to egg production with a lower gauge increase of 1/8 inches. This result assumes that V-notching has no adverse effect on reproduction, growth, and survival and that V-notches are maintained until death. No one has examined whether V-notching itself delays molts, changes extrusion rates or increases mortality. If any of these prove significant (and if V-notched lobsters are not re-notched after a few molts), the benefits from this program could be overstated.

An important issue associated with a complete dependence by the state of Maine on V-notching is that the current number of V-notched lobsters in the population is not known. Adoption of a policy of complete dependence on V-notching for stock safety would require a monitoring program to ensure sufficient levels of reproductive V-notched lobsters are being maintained in the population.

These results point to several areas of lobster biology critical to effective management, but which are still poorly understood. Some of the outstanding uncertainties are amenable to further research. An important area that could benefit from further research is the effect of V-notching on lobster growth, reproduction and mortality. Another area in which research should continue is the issue of offshore migration. Further information on growth, mortality and migration could be obtained by additional analysis of DMR size distributions.

Some of the areas in which research by the state of Maine is unlikely to bring short-term (less than 5 years), inexpensive rewards would be natural mortality rate and the source of Maine's recruitment. The former is probably impossible to determine because of difficulties in measuring natural mortality in fished populations. The latter is an important problem and should be pursued, but it will be long-term and expensive. The issue could possibly be approached in cooperation with other states and Canada.

In attempting to weigh each of these options against the other, we have come to the conclusion that no one policy stands out as a clear "best" alternative. Both V-notching and gauge increases add to egg production and thus increase stock safety. Gauge increases have the added advantage of increasing total yield and altering catch composition towards larger, higher valued lobsters. These benefits do not come without sacrifice however, since some short term yield decreases must be absorbed before the gains are

earned. It is possible to tailor the approach to a gauge increase in many ways, however, including a very gradual increase whose first year costs would be less than the normal year-to-year variation in a catch. As an "investment," a gauge increase is probably worthwhile by any reasonable standards.

There is considerable support among fishermen for the V-notching program as a means of maintaining egg production. As we have found, their support is well-grounded since V-notching could potentially add to egg production. There are some important unknowns involved yet which ought to be investigated in parallel with any program relying solely on existing practices or on stepped-up programs. Chief among these are the impacts of V-notching on lobster reproduction, growth and mortality, and studies of the overall abundance of V-notched lobsters in the population.

A final observation is that there is a considerable amount of antagonism and dissension among major participants which is as much an impediment to effective management as is the lack of scientific understanding of some processes. There are inherent reasons for some of this conflict, and much of it is associated with a structure which has evolved that is basically adversarial as opposed to cooperative. In addition, because this system is complicated and often counter-intuitive, there are misconceptions and misinterpretations of observations that need to be resolved to the satisfaction of all participants. We have identified some important widely held and controversial beliefs that are particular sources of disagreement. Probably the most significant controversy is over the number of V-notched lobsters in the Maine population. A second question is whether lobsters leave the Maine fishery when they become sexually mature. The only evidence for permanent migration is from a tagging study in which 10 to 15 percent appear to have migrated permanently. A third is that since the size of maturation is so far above the lower gauge, moving it up will have an insignificant effect on egg production. This is only "half true." While the actual numbers by which egg production is increased are small compared to possible egg production with no fishery, the model results show that gauge increases contribute the same order of magnitude increases to egg production as any of the possible management options. A fourth significant belief is that stable catches or the slight recent increase in catch is evidence that the stock is safe. Absolute safety is as impossible to determine as a collapse is to predict. The fact that something has not yet happened is not good evidence that it will not.

While we have addressed most of these issues in this report in more detail, we suspect that debate over them will continue. These are only examples of the kinds of issues that need to be resolved in order to forge consensus in the Maine lobster fishery.

I. Introduction

Nearly 90 years ago Francis Herrick (a distinguished lobster biologist) chastised both legislators and lobstermen alike in Maine for merely paying lip service to considerations aimed at maintaining a healthy and viable lobster industry. Herrick claimed that "personal interests, imperfect knowledge of the habits and needs of the animal itself, and perverted logic have characterized much of the legislation that governments have enacted for the preservation of animal life." He predicted not only "gradual but certain decay" in the industry, but also the precise mechanisms by which this might happen if better sense did not prevail. He recommended some severe legislative measures, including closed seasons over 5-year intervals in designated areas, a minimum size limit, and modified traps to allow undersized lobsters to escape. Much of Herrick's gloomy prognostications for the industry and his proscriptions for saving it were scorned by lobstermen. As two historians recently put it, "for one thing, biometrical arguments such as Herrick's on behalf of minimum size were a bit too technical to penetrate the workaday level of the fishery. For another, their conclusions, while logical, were necessarily founded on a small, recent data base, and therefore were not definitive. After all, ... what did laboratory experts know about the realities of lobster life in the wild?" In addition, "when the immediate livelihood of fishing families was at risk, how many could reasonably be expected to keep the big picture in mind?"

A cynic might read these words and conclude that we haven't progressed very far over the 90-year period which has passed since the first regulations were imposed in the Maine lobster industry. We are still hearing, for example, dire warnings from many biologists about the precarious status of the stocks. These warnings are still countered by equally vocal lobstermen who appear to mistrust scientists generally, or who interpret the data differently, or who believe that the short term sacrifices recommended by biologists are too great. In this high stakes dispute, legislators are caught in the middle of a barrage of conflicting opinion and unenviably, in the position of having to both arbitrate and choose a course of action for the fishery. This report is intended as an informative guide to the issues pertinent to this decision problem.

II. Background Issues

A. Perspectives - Lobstermen vs. Managers and Biologists

Before attempting to sort out fact from fiction, it is worth setting the stage a bit by discussing some basic background issues which lie behind today's (and the past's) lobster policy disputes. We feel this is necessary because, at first glance, it might seem surprising that lobstermen are still clashing with managers over the same issues which were being debated 90 years ago. Since these basic conflicts appear to be so ingrained in this system and since they also appear to be real impediments to progress, it is worthwhile spending some effort trying to understand them.

Throughout the history of lobster policy debate in Maine, there has been a tendency on the part of both lobstermen and managers to dismiss each others' arguments as uninformed, naive, or self-serving. This occurs in spite of the fact that both groups have a basic interest in the preservation of a viable population in the long run. One might wonder how individuals with the same basic interests can be so vehemently at odds over policy issues. In talking with industry and management representatives, we found genuine and honestly held convictions that often led people to disagree over what policy courses ought to be adopted at present. These disagreements fall into three classes. First there are instances where, because of complexities and unknowns, people simply do not fully understand the system--either the biological or the economic/marketing components. In the face of these uncertainties, people in the lobster industry do what most people do in similar situations, e. they make educated guesses about processes and parameters. We found a variety of opinions about biology, economics, and the management process which reflected an equally rich variety of experiences, prior thoughts, and general open mindedness. Many of the "educated guesses" appear to be correct but some are incorrect and a few cannot be verified with the current state of knowledge. Second, we found some clear differences over what the objectives of lobster management policy ought to be. These differences are, to a large degree, determined by the nature of the interaction among participants on the industry (see Section B below). Finally, we found instances where people had different interpretations of the same "facts" and/or different conclusions about the implications of these same facts for policy choices. In those cases, again, it appears that some of these interpretations are correct whereas others are not. In the final analysis, much of the conflict in this industry seems resolvable only if the basic atmosphere between lobstermen and managers can be changed to encourage open interchange. Much of the current stalemate is occurring because participants have fallen into adversarial positions over issues rather than trying to work toward consensus over the issues.

B. Fisheries - Common Property Incentives

Talk to any lobsterman about the positive aspects of fishing and he will extol the virtues of independence, of being out on the water, of the excitement of contesting nature, etc. Ask about the negative aspects and you will also receive a litany of comments about price manipulation by dealers and marketers, about overregulation, about how difficult it is to make a decent living, etc. In many ways, in fact, lobster fishing is much like farming and indeed one gets nearly identical lists of prospects and problems when one interviews either group.

In a very important sense, however, lobstering is very different from farming or other conventional occupations connected with resource use and the outdoors. This difference is so fundamental that it deserves special emphasis because it is at the heart of much of the current conflict in the industry. The main difference between lobstering and many other industries is that lobstering is an open access, managed, common property industry--"common" as opposed to private property in that no one "owns" lobsters and/or lobster grounds. The importance of this fact is that the basic incentives that drive behavior in lobstering are substantially different

than those faced by (for example) farmers. In particular, the amount of fishing effort expended in an open access common property resource tends to expand far beyond what any single or group of individuals might choose to apply were they exclusive "owners" of the resource with the ability to exclude other non-owners from resource use. Roughly speaking, whereas "private" owners would stop with the number of boats, traps, trap set over days, etc. which yielded the largest total profits, in a common property situation more effort is drawn in until costs are driven up to essentially equal revenues from fishing.

The implications of these differences in motivation have been analyzed for a considerable time over many case studies. Most economists have focused on what is called "rent dissipation"; namely, the lost "potential" profits or "rents" which are foregone when more people and gear enter and drive costs up. Biological scientists have focused on the potential danger to the stocks when effort levels rise to a point whereby too large a fraction of available biomass is captured.

To a large extent, management measures have evolved in most modern fisheries to address the biological consequences of open access common property incentives. In some fisheries, a total allowable catch is determined which is deemed to allow sufficient numbers of reproducing fish to escape and provide "recruits" to future fisheries. In these fisheries the season length is often managed to ensure that, with the effort available in the fishery, the total allowable catch is not exceeded. As the value of the fishery increases, effort expansions are "mitigated" by reducing season length. In other fisheries, a minimum mesh size is set to ensure escapement of enough fish to provide a brood stock. In these types of management regimes, as effort increases, the mesh sizes (or other controls) are often adjusted to maintain enough survival. The lobster fishery in Maine is managed in this second manner, of course, with no controls on effort or seasons but controls on the sizes that may be taken. The basic biological management issue is whether existing measures (including size limits) allow enough escapement from the fishery to ensure an adequate brood stock.

Much of this is elementary and familiar to anyone involved in fisheries. What is often not appreciated however, is that managed, open access, common property resources are almost inevitably destined to produce an abnormally high level of conflict among participants. Lobstermen, on the one hand, are squeezed in a highly competitive struggle over the resource between themselves. In effect they are competing for a fixed pie, the dimensions of which are set by the regulators and managers whose activities basically serve to constrain the options of lobstermen. Managers, at the same time, have as their basic goal preserving the species at a viable level in the face of both high levels of fishing pressure and potential environmental perturbations. In a very important sense both parties are forced into an arena in which they are at odds even though they have common long term interests in promoting species viability.

Given this basic decision-making arena, it should not be surprising that lobstermen and management biologists have difficulties agreeing on the "facts." In the first place, the inherent motivations which guide their

individual actions are very different. Lobstermen are involved in an increasingly competitive struggle with each other over a fixed resource. As prices rise and more entrants and effort is attracted, the intensity of the competition increases and the struggle to earn a reasonable income becomes more severe. In this situation the very suggestion of any outside measure which would disrupt an already precarious situation for an unknown future benefit is understandably unpopular. Management biologists, on the other hand, see their main responsibility as "protecting" the stock against fishing pressure and environmental perturbations. As they see fishing effort intensifying, their objective of maintaining a "safe stock" is increasingly threatened and they begin searching for measures to rectify the "problem." In view of these factors, it should not be surprising that proposed policy changes which seem beneficial should provoke such heated response. In particular, simple terms such as "stock safety" become loaded with importance when, for lobstermen, attaining a "safer" stock also requires adopting policies which alter a position of apparent relative security.

The unfortunate postscript to this scenario is that things will only get worse as time passes. As the human population, income, and the demand for lobsters grow, the real price and consequent value per lobster will increase. As value increases, even more effort will be drawn into the fishery, intensifying competition between lobstermen and exacerbating the inherent conflict associated with managing the resource. Thus even though expectation of industry participants (both lobstermen and managers) are that emerging problems will blow over in a few years, it is inevitable that the conflicts will escalate over time.

C. Stock Safety

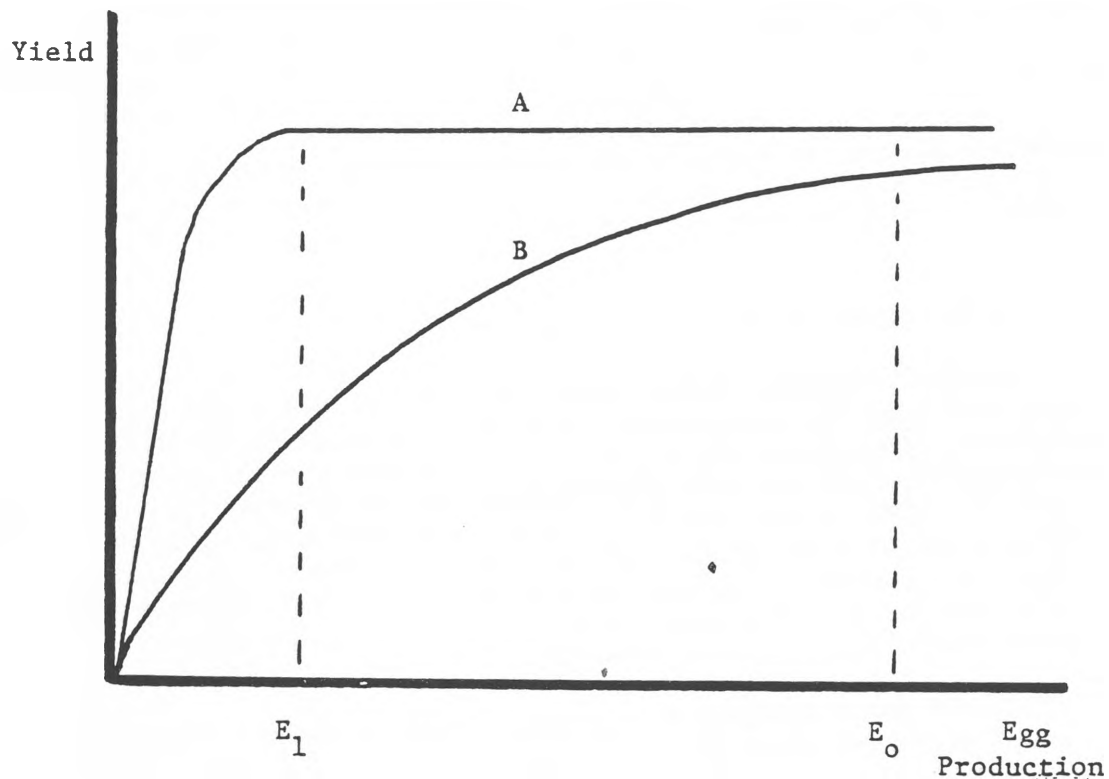
Since the issue of "stock safety" is of some importance, it bears discussing just what this idea means. For ease of understanding it is convenient to first ignore any environmental perturbations that might affect lobster. In this case, each lobster would proceed through a life cycle from egg to larva to recruit into the fishery. For a species to maintain itself under fishing pressure, enough lobsters must "escape" the fishery each year to bear eggs which subsequently turn into larvae and then enter as recruits to the fishery. It is possible for this system to maintain itself in such a state that it can go on indefinitely, i.e. a constant number of recruits enter the fishery each season as a result of a eggs being fertilized several seasons ago, these eggs in turn resulting from the escapement from the fishery in that and previous periods, etc.

A critical link in this system is the one between the brood stock and recruitment. As the brood stock is reduced, total egg production will decline. This does not necessarily mean that the number of recruits to the fishery will decline. Most biologists believe that even when egg production declines,

over some range at least, the same number of recruits will be produced. Beyond a critical point, however, increased pressure on the brood stock, which results in fewer eggs being produced, will reduce the number of recruits to the fishery. This process is illustrated below in

Figure 1. The possible response of numbers of recruits to egg production is depicted as two hypothetical relationships (Curves A and B).

Figure 1: Hypothetical Stock/recruitment relationships and stock safety.



The first uncertain and controversial issue is whether lobster biology is better depicted by curve A or B, that is, as the brood stock decreases, will the fishery give warning that the population is falling (curve B) as numbers fall below E_0 ? Or will the fishery collapse catastrophically and without warning as might occur if the biology looks like A and we are at E_1 .

Current knowledge about stock/recruitment relationships is very incomplete. There are opinions expressed which tend to fall into the camps that would be expected given our discussion of the basic motivations of the players involved. Those management biologists who are particularly worried believe that we may be at E_1 on Curve A. Their conclusions are based on several lines of logic. First, the current fishery has a minimum carapace length which allows harvesting before many lobsters have become mature and extruded eggs. Thus the only lobsters left for brood stock are those which "escape" the fishery. As fishing effort has intensified fewer lobsters have escaped and there has been heavier fishing mortality on those that manage to escape the fishery during their first and subsequent years. It is thus logical to expect that, other things equal, egg production must be declining

as fishing pressure has risen. The few attempts to calculate how many eggs must be being produced suggest that current egg production must be very low. The possibility exists, of course that other factors (e.g. larval transport from offshore stocks), may be supplying the deficit egg production.

Others who counter these arguments paint a picture that either we are still at E_0 (with either curve), or that offshore stocks are supplying enough recruitment so that we need not worry about providing a sufficient brood stock for the inshore fishery. The evidence in support of this reasoning is the demonstrated stability of catch over the past 30 years. It has also been suggested that the V-notching program has been a significant source of additions to the brood stock—enough, in fact, to counter lobsters lost as effort has expanded over the past decade or so. Thus, in their view (perhaps colored by fears of the costs of moving from an apparently "safe" status quo) there is insufficient evidence of impending catastrophe to warrant the (potentially) bitter medicine of change.

D. Boundaries of Analysis--Us vs. Them

Another important background issue which colors the analysis of this problem concerns the geographic scope held as relevant by various individuals. Biologists typically view as "their system" the species at large, encompassing any interconnections across state or national boundaries as well as offshore and inshore stocks. Fishermen, quite naturally, have a somewhat smaller view of the relevant decision arena. For example, there is currently reluctance to support conservation measures inshore among those one who believe that the benefits will accrue to different lobstermen offshore and/or across state boundaries.

All of these "boundary" problems would be easier to deal with if we knew with certainty more about lobster migration patterns. Unfortunately, evidence from existing studies is not conclusive and hence most lobstermen have taken a conservative and parochial perspective. For example, much of the reluctance of inshore fishermen to support a carapace length increase is founded on the belief that protected lobsters will simply migrate southward and eventually will migrate to the offshore fishery. Thus the feeling is, why should we sacrifice if all of the benefits go to others? Similarly, inshore fishermen are unwilling to release offshore fishermen from the constraints of the upper size limit because they believe that offshore lobster brood stocks may be feeding inshore fisheries with larvae. In both of these cases, the basic confusions surrounding movement behavior of lobsters allows the existing "evidence" to be interpreted in many ways. Lobstermen, fearing high sacrifices associated with certain policies, are also unsure of the benefits that they might gain. If even some of these benefits are anticipated to accrue to "outside" groups, policy change takes on an even more risky character.

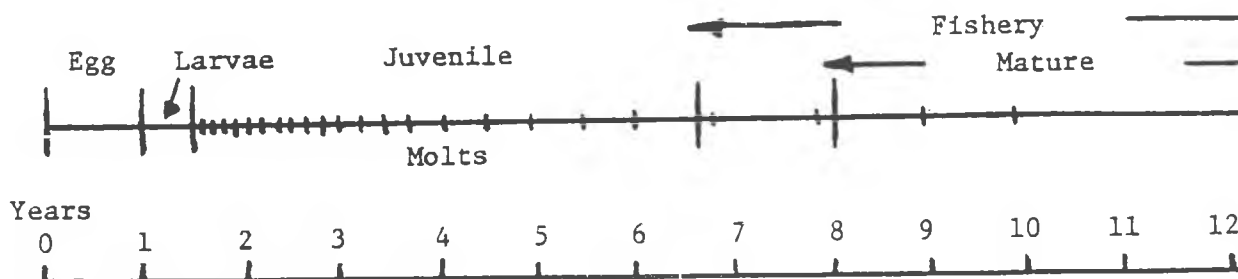
III. State of Our Understanding--Lobster Biology

A. Lobster Biology--Life History of the Individual

1. Stages of Life Cycle

The basic lifecycle of lobsters proceeds as outlined earlier; namely a process of development from egg to larva, to settlement, and to recruit (see Figure 2). Females carry eggs for about 12 months. After hatching, larvae spend several months in the plankton, and then they settle on the bottom. Here they go through about 20 molts over the 5 to 7 year period that it takes them to reach legal size. Lobsters do not begin to reproduce until they have been exposed to the fishery for at least one year.

Figure 2: Life stages of lobster development.



2. Recruitment-Maturity, Fecundity, and Larvae

Population biologists focus on recruits because they are typically of primary importance to population dynamics. Fluctuations in year class numbers usually take place before the age of recruitment. Total recruitment in any year begins with egg production. Total population egg production is the sum over all sizes of the number of females at each size times the number of eggs produced by individuals at that size. The number of eggs produced by each female lobster is roughly proportional to weight, but lobsters don't start producing eggs until they become sexually mature. The estimated fraction that are sexually mature at each size is shown in Figure 3.A (from data in Krouse (1973) which are similar to data in Campbell and Robinson (1983) for the Bay of Fundy shown in Figure 3.B). After maturity, females generally carry eggs every other year. There is some evidence of older lobsters in laboratories carrying eggs more often, but this has not been demonstrated in the wild.

After the egg stage, the next step in the recruitment process is the larval period. After the eggs hatch the larvae move up to the plankton where they remain for several months. Very little is known about what they do and where they go during this stage (see Fogarty 1983, Harding et al. and Hudon and Fradette in Lobster Recruitment Workshop (LRW)). Larvae are at the

Figure 3.A: Maturity ogives* (from NEFMC after Krouse (1973)

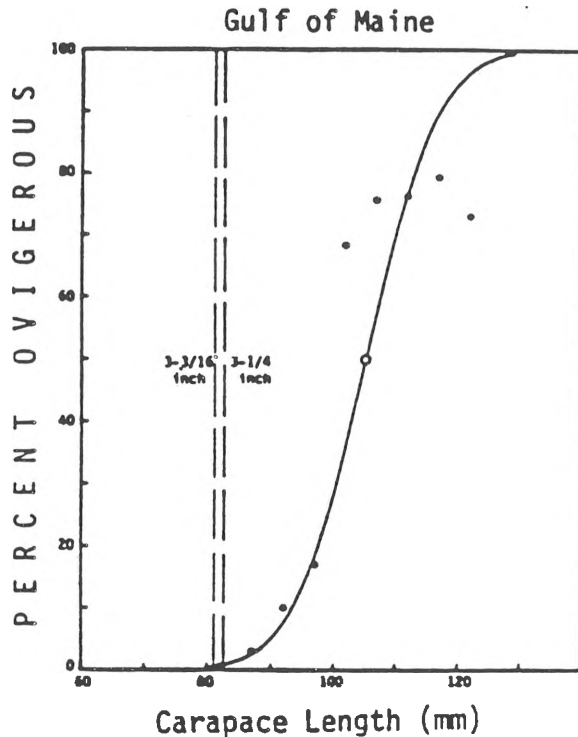
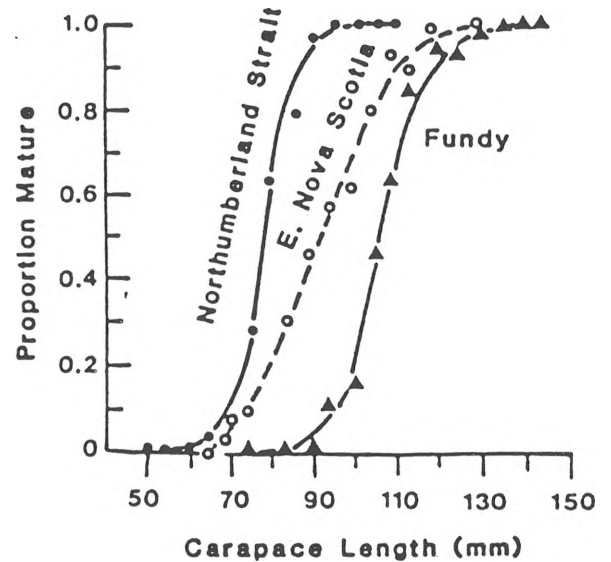


Figure 3.B: Maturity ogives* (Campbell and Robinson 1983).



Maturity curves (Northumberland Strait, eastern Nova Scotia, and Bay of Fundy) based on developed cement glands on pleopods, which indicate that egg extrusion is imminent.

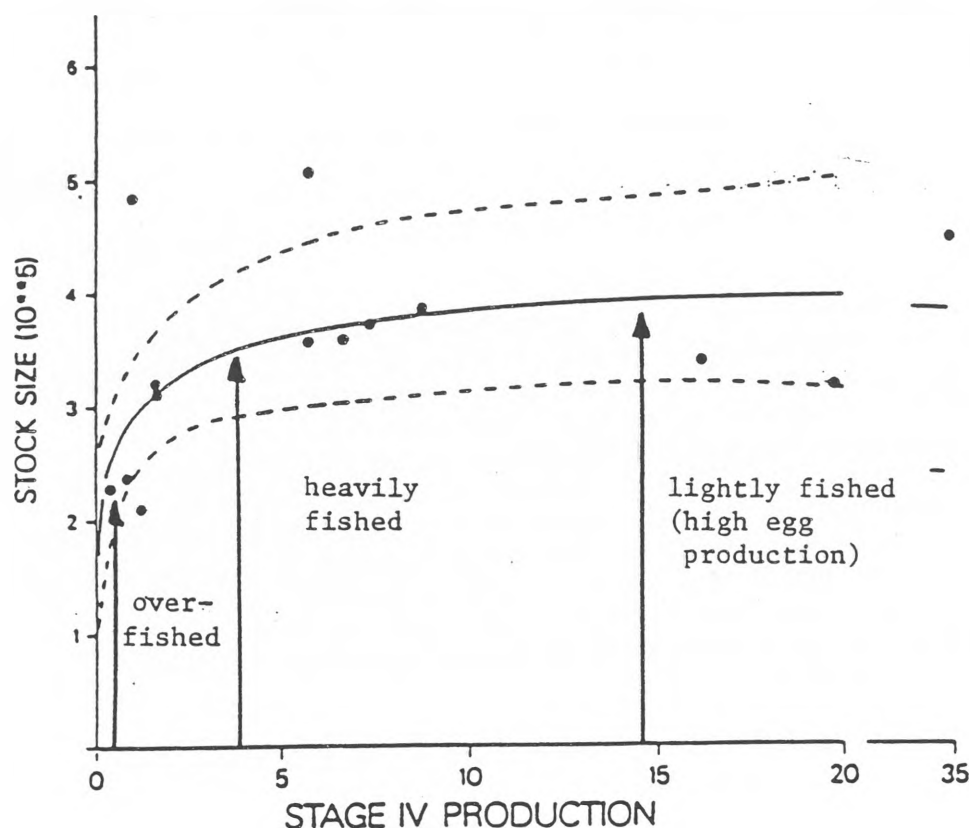
*Maturity ogives show the percent of lobsters sexually mature at various carapace lengths (in mm).

mercy of the currents but their actual transport depends on how deep they are (i.e., currents can flow in different directions at different depths). It is generally believed that larvae will follow the counter-clockwise surface circulation pattern during the spring in the Gulf of Maine, but this has not been demonstrated.

Following the larval phase, the next step in the process is settlement. This phase is also poorly understood. One of the ways that fisheries scientists have characterized this phase, (even if they don't know exactly what happens during settlement) is to plot the numbers that survive this phase as a function of the numbers that enter this phase. The numbers that survive this phase are usually assumed to be proportional to the catch 5 or 6 years later. An example of such a plot is shown in Figure 4. As can be seen, recruitment appears to remain relatively constant even when total production of stage IV larvae (the last larval stage) varies over a considerable range. From these results it has been suggested that settlement-stage lobsters are limited by some fixed factor (e.g., spaces on the ocean floor to hide from predators) and that egg production and pre-settlement numbers can vary over a large range without appreciably affecting the number in post-settlement survival. As Figure 4 shows, however, there

may to be some lower limit of stage IV numbers below which recruitment falls off dramatically. At this critical level, further reductions in egg production and consequent pre-settlement larvae appear to have very substantial impacts on numbers and in a manner shown in Figure 1 (Curve A). This type of evidence has given biologists concern over the possibility of a sudden and unforeseeable "collapse."

Figure 4: Some Evidence on Recruitment/Stage IV Relationships (Fogarty LRW).



Relationship between stage IV larval production and weighted average of subsequent stock size 5-7 years later (Scarratt 1964, 1973). Solid line indicates predicted relationship. Dashed lines indicate 95% confidence intervals on mean predicted value. Circles represent observed values.

3. Growth and mortality

Those lobsters which survive to settlement are recruited to the population. In this phase they grow and are subject to various types of mortality and eventually reproduce if they survive long enough. The yield

of a fishery and particularly its size distribution are thus intimately dependent on these factors combined.

Growth is obviously of primary importance in analysis of the fishery and the maturation process. Since lobsters grow in discrete jumps when they molt, the growth process is more complex than the smooth increase in size seen in fish. To simplify calculations, fishery biologists have generally used a smooth curve to approximate the growth of crustaceans. Although most of the growth descriptions used in lobster management studies use this simplification, we prefer to describe growth as it actually occurs since the smooth approximation may lead to inaccurate assessments of policy impacts.

A more realistic way of describing growth is by describing the percentage increase in length per molt and the fraction that molt each year both as functions of size. This has been done recently by Campbell (1985) for the Bay of Fundy and we also employ this description (with the Maine data) in our model.

There have been several different estimates of growth rates in lobsters. Since we are interested in evaluating policy changes around the lower size limit, the relevant growth rates are those near 3 and 3/16 inches in length (81 mm). At this size available evidence suggests that lobsters in Maine grow 14 to 15 percent in length at each molt and almost all of them molt each year. Thus annual growth in length should be near 14 percent per year. Growth rates assumed previously by population biologists for lobster growth in Maine (Thomas 1973) has them growing at 11 percent (the annual increase at 81 mm in the von Bertalanffy model). Other estimates in New England range from 12 percent per year in southern New England to 22.5 percent per year for offshore males (American Lobster Fishery Management Plan (FMP)).

The second critical process to the life history of the individual lobster is mortality. Fishery biologists describe mortality in terms of "instantaneous" mortality. Since this term is somewhat abstract we will translate instantaneous mortality figures into the fraction that dies (or lives) each year. Annual mortality consists of two parts: natural mortality and fishing mortality. The latter has been estimated several times for Maine stocks (Thomas 1973) and for other lobster stocks. (See reviews by Campbell and Anthony in Anthony and Caddy, 1980 and the FMP). The instantaneous value is high for both the inshore stocks (greater than 2.0 which means that ninety percent are caught each year) and the offshore stocks (possibly as low as 1.5 which means that about 80 percent are caught each year). For our purposes, the existing estimates are adequate.

The natural mortality rate is much more important in calculating the harvesting effects of changes in size limits. This parameter has been estimated several times by Thomas (1973). The values obtained by him through various methods are 29.3 percent dying per year, 19.2 percent per year, 22.9 percent per year, 7.7 percent per year, 43.9 percent per year and several estimates that were less than zero. Others have estimated values over the same range. Natural mortality is extremely difficult to measure in fished populations, and there is no way to choose which of these

is correct. Although Thomas eventually concluded that he preferred the value of 10.0 percent and virtually all researchers refer to that value as the "most likely", the value of natural mortality is best regarded as unknown. We can however, put certain limits on its value and most biologists would agree to a range between 5 and 25 percent per year.

4. Migration and Movement

There have been several studies of lobster movement in the Gulf of Maine. Many earlier studies are not well suited to a firm understanding of patterns of movement, however, because they were single recapture studies. In these studies, most lobsters were immediately caught before they had much chance to move. More recently, multiple recapture studies have been initiated in which tagged lobsters are returned to the sea after being recaptured. Although results from these studies are still biased by the fact reported locations of captures depend as much on the distribution of fishing effort as they do on lobster distribution, these studies do allow a better look at long term movement than single recapture studies.

While early studies led to the conclusion that lobsters did not move much, recent studies (e.g. Dow, 1974; Campbell et al, 1984; Campbell and Staska 1985; Pezzak and Dugan LRW; Meyer et al. LRW; and Daniel et al. LRW (1985)) have shown that most lobsters do move at least a short distance. These movements appear to be inshore-offshore (on a seasonal basis) over distances less than 20 miles. A certain percentage of tag recoveries show movement over much longer distances, primarily by larger mature lobsters.

The recent and ongoing work being done by the University of Maine, the DMR, and the lobstermen is the most relevant to the questions we are addressing here. Analysis of second year returns from the first year's tagging shows 89% of the tags were recovered within 20 miles and are generally consistent with seasonal movements mentioned above. Of the 11% (29 lobsters) moving longer distances, 4 were later captured near their original release site. The direction of movement was generally to the southwest for the larger lobsters moving longer distances. The preliminary results reported in Daniel et al. (1985) also show that the percentage of lobsters in each size class migrating long distances increases from 10% for those with carapace between 89-93 mm, to 13% for those 94-98 mm, and to 15% for those 99-103 mm. Thus, the percentage migrating increases as size ranges increase, but not dramatically. These results should be interpreted with caution, of course, since the numbers of large lobsters sampled to date is small. Future studies should allow us to pin down with more statistical accuracy the patterns of movement among lobsters of different sizes.

B. Population Dynamics of Harvested Populations

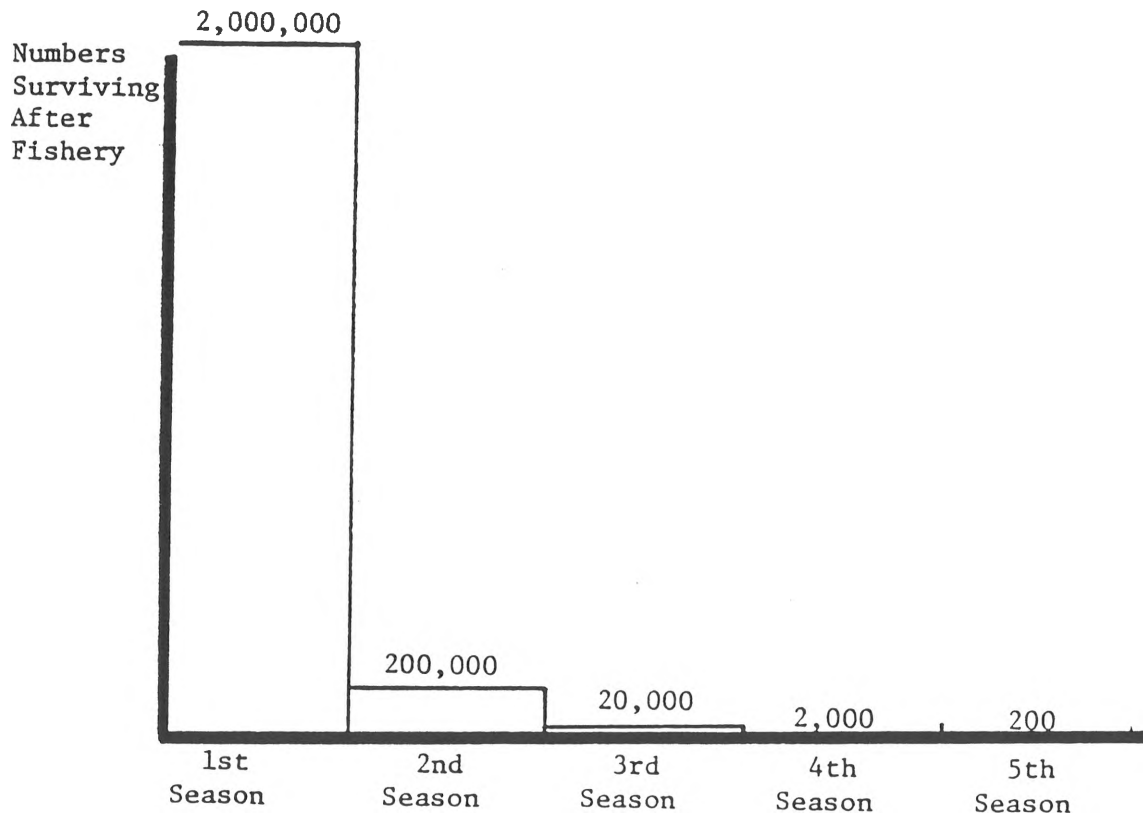
Given basic knowledge about how each individual lobster passes through various stages of its lifecycle, we may now move to discussing how everything fits together in a population. It is important to keep aspects of individual life histories separated from those of the population because

often facts do not carry over simply when looking at the whole system of individuals.

The first issue is how fishing affects the numbers of lobsters and their size distribution. As discussed above, following the settlement lobsters go through numerous molts until they reach the size (currently $3\frac{3}{16}$ inches) at which they became subject to removal via the fishery. Moreover, the number of recruits which have entered the fishery appear to have remained more or less constant ($\pm 20\%$) over the past decade or so. If we think, therefore, of a process whereby a constant number of recruits enters the fishery each year, and that the fishery and natural mortality combined take about 90% of these, we can calculate how many will "escape" the fishery in the first year and subsequent years. The answer is that not very many escape, of course.

For example, if we follow through 20,000,000 lobsters (a typical year class), the fishery and natural mortality will take a combined 90 percent of these during their first year of exposure to fishing. In the second season of this group's life cycle, the 2,000,000 that "escaped" during the first year will be cut to 200,000 by the end of the season and so on. By the end of the sixth season, there will be only 20 lobsters left out of the original group of 20,000,000. Thus not many lobsters escape to become very large when fishing mortality is high. In Figure 5, the numbers surviving after exposure to several years of fishing is shown.

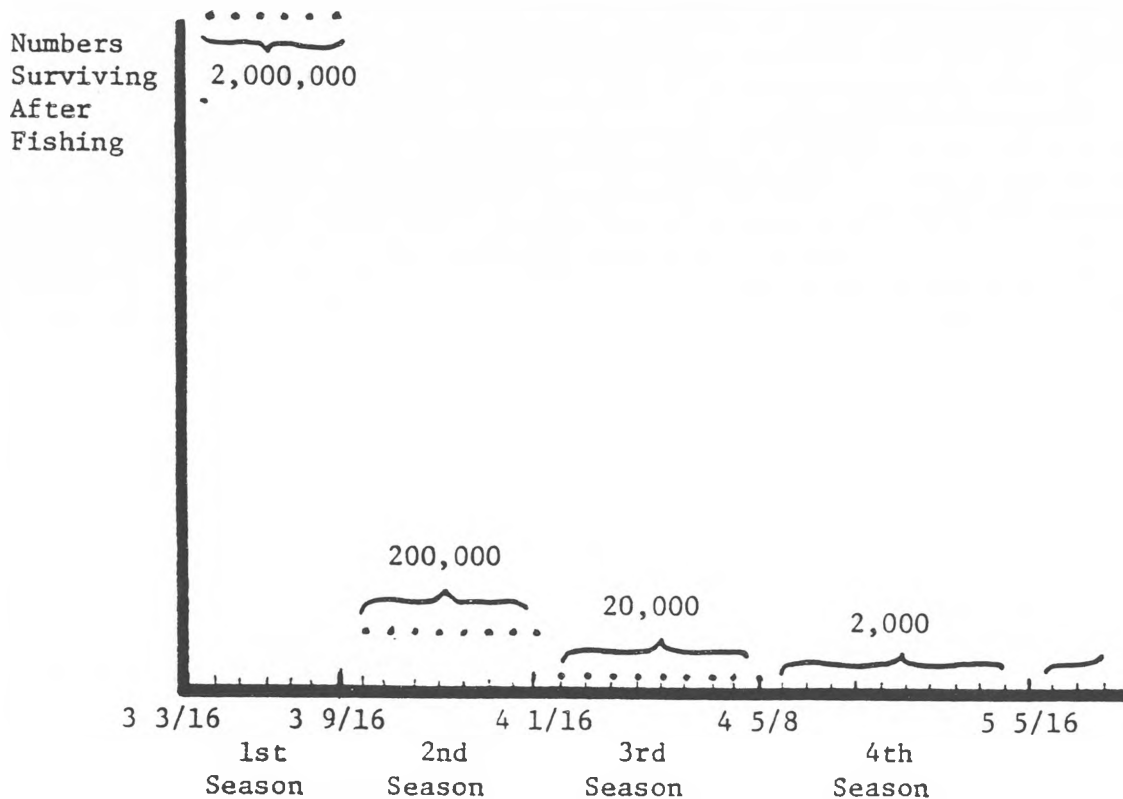
Figure 5. Numbers Surviving in a Typical Year Class After Successive Fishing Seasons.



The second feature of a fished population to note is that there will be a more or less stair step pattern in the numbers of surviving individuals at different sizes. This arises because a given year class will enter each year's fishery with a roughly uniform range of different-sized lobsters in it. For example, of the 20 million lobsters who first become subject to capture, there will be some lobsters just at the minimum legal size of $3 \frac{3}{16}$ inches. These lobsters will have been 14% smaller or about $2 \frac{13}{16}$ inches last season (since they molted 14% up to $3 \frac{3}{16}$ by this season). At the same time, there will be roughly an equal number of lobsters first subject to capture at a size of about $3 \frac{9}{16}$ inches. These will be the ones which just escaped being caught last season when they were slightly less than the legal minimum of $3 \frac{3}{16}$ inches. In between these two sizes, there will be roughly equal numbers in groups between $3 \frac{3}{16}$ and $3 \frac{9}{16}$ inches, the result of lobsters which molted up to these sizes since last season.

Similar logic applies to lobsters that have survived through several seasons of effort. Thus the post-season population of survivors should look something like Figure 6.

Figure 6. Population Abundance by Size After Fishing.



Note that each "step" has a length which reflects the 14% growth rate that lobsters experience per molt. In addition, the total numbers in each step are only 10% of those in the previous step since fishing and natural mortality eliminate 90% each season.

As can be seen, after each season there should be roughly 2.0 million lobsters in the $3 \frac{3}{16}$ - $3 \frac{9}{16}$ size range, 200,000 in the $3 \frac{5}{8}$ - $4 \frac{1}{16}$ range, 20,000 in the third range and so on. To determine how many eggs this system produces, we need only determine how many females are mature at each size class, how many eggs are extruded at that size, and add these up over the whole population. Available evidence on maturity suggests that the midpoint of the maturity curve (where 50% of the females are sexually mature) occurs at a carapace length of about 100-105 mm (see Figure 3A and 3B) or about 4 inches. By applying these figures to the brood stock data as calculated above, we can find total system egg production. Note that, again, there are not many large lobsters left to be reproducers. First of all, half of the numbers enumerated above are males. Secondly, the bulk of the females escaping (in the first year escapement group) are in the 81-93 size class where less than 7-8% are sexually mature. On top of this is the fact that each female lobster typically extrudes eggs only every other year.

These ideas are basically enough to point the way to how to model and forecast the implications of changes in this system. Even these simplified graphs point out several conclusions of a qualitative nature. For example, if the minimum size is left where it is and effort intensifies (because of rising prices, for example), the step lengths will be unchanged but the height of the steps will be lower. If effort increases to the point where combined fishery and natural mortality total 95%, for example, the steps would be half as high--leaving 1 million plus 100,000 plus 10,000 etc.* escapement from the fishery. Similarly, the effects of a carapace length increase will be to shift to the entire set of steps to the right by whatever increment is chosen. Basically, a carapace length increase shifts more lobsters into the sizes at which greater fractions are mature. In the same vein, V-notching and berried protection "removes" a certain fraction of the population from being subject to the harvest--in effect creating two populations of females with different effective (fishing plus natural) mortality rates.

Beyond these simple and general conclusions, it is possible to use the above ideas to think through the qualitative characteristics of a lobster population subject to any degree of complexity one wishes and, ultimately, to predict the quantitative impacts of various policies. For example, we can keep track of separate populations of males and females, a necessary first step in calculating egg production and the effects of berried female protection and/or V-notched female protection. The upper size limit can be accounted for by noting that those lobsters (of the very few) above 5 inches are not subject to fishing mortality but only to natural mortality. A complete description of the fishery needs to include many more details and complexities such as length to weight relationships, molting frequencies, maturity information, egg production, etc. and hence a computer model is certainly a necessary aid to understanding such a system in its full detail. In Section V, we discuss the results of our modeling exercise of various options for the Maine lobster fishery. Before presenting these, however, we discuss some important issues which can be addressed, at least in part, by what we know up to this point.

C. Common Misconceptions

As discussed above, it is easy to make incorrect generalizations about how a population will behave by simply extrapolating information about individual lobsters. In particular, it is easy to be misled into believing some of the following:

1. Since we do not catch many big lobsters anymore, it must be the case that all lobsters over a certain size permanently migrate offshore (where big lobsters are caught).

This is not necessarily correct. What is actually being observed may be due instead to the differences in fishing mortality on- and off-shore. That large lobsters were once found in inshore waters is documented in histories of the fishery before it began to be heavily exploited. As we showed above, with high exploitation rates it is virtually impossible for large lobsters to slip through the fishery very many times. In fact, the odds of a given lobster surviving through some number N seasons inshore is only $(0.10)^N$. For example, since it takes four seasons in the fishery for a lobster to -attain a size above 5", the odds are one in ten thousand that it will reach that size. It is thus not surprising that inshore lobstermen do not see many large lobsters--most have been caught before they could attain any significant size. In contrast, in a fishery with lower exploitation rates, the chances of large lobsters surviving is much greater. If the combined natural and fishing mortalities are 70%, for example, the odds of the same lobster surviving 4 seasons and attaining 5" is 80 times greater.

2. Stable catches are evidence that the population is "safe"

Current stocks may or may not be safe but recently stable catches are not a reliable indicator of relative safety. Recall that available evidence suggests that it is possible to reduce egg production and settlement-stage larvae significantly before an impact is felt on recruits to the fishery. Perhaps more important is the evidence that there is a lower threshold below which recruitment will be dramatically reduced by further declines in egg production. Thus a major issue is where we are on the egg versus recruitment curve (Figure 4). What we do know is that fishing effort has intensified substantially over the past 10-15 years and as a result the exploitation rate has risen (to current estimates of 90%). As we showed above, this high an exploitation rate leaves very few lobsters to escape into the breeding population and become egg producers. The feedback from declines in brood stock to declines in subsequent recruitment is on the order of 5-7 years, however, so that it is possible to push egg production beyond the threshold and not experience the decline until several years later.

Unfortunately, no one knows exactly where we are on the stock

recruitment curve. The best we can say is that measures taken to produce more eggs would make the fishery relatively "safer"—both in pushing it away from the threshold if it is close and also in providing a buffer of extra eggs to protect against environmental perturbations. Essentially this is, and will remain, an issue of judgment. It is important to realize, however, that current stability does not necessarily imply that the fishery will not collapse catastrophically next year or several years from now.

3. Since very few lobsters are mature at 3 3/16 inches, we need a large increase in carapace length to get any significant increase in egg production.

The impact of a gauge length increase on egg production depends upon a host of factors including size distribution of the population, size at maturity, and fecundity (numbers of eggs produced). A carapace length increase shifts the size distribution towards larger sizes as shown in Figure 7.

What is gained, therefore, are increases in numbers of animals at the right edges of each carapace length group. These gains would accrue, for small increases of say 1/16 inch from the present 3 3/16, in animals at sizes around 3 5/8, 4 1/8, 4 11/16 inches, etc., where percent mature are not inconsequential. A more precise forecast of egg production requires a model to capture all of the details but as we show below, even small increments can yield significant increases. These increases may appear small when compared with possibilities in an unfished population (e.g. none of the proposed management options raise egg production to more than one percent of its unfished level) but they are substantial when the reference is the existing egg production (i.e. they can double or triple it).

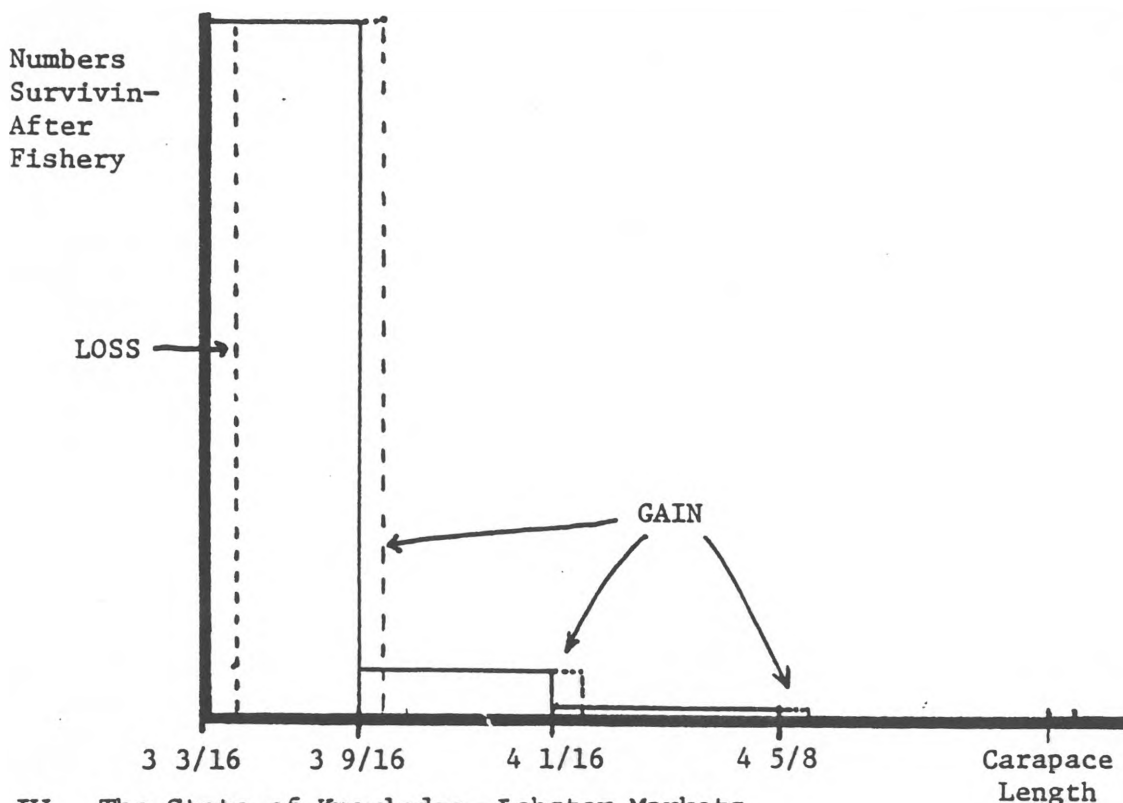
4. Since the ratio of V-notched to landed females is 0.3 (e.g. in the UMO/DMR study) and about 8 million females are landed in the fishery each year, there about 2.4 million V-notched lobsters in the population.

This statement exemplifies some of the confusion over the V-notching program and points to the need for a model to predict the complexities involved. The problem with this argument is that it mixes "apples and oranges" by confusing catch and abundance. To obtain an accurate estimate of abundance of V-notched individuals, one needs to multiply the ratio of V-notched to landed lobsters by total abundance and not annual catch. In addition, as the season progresses, the number of newly recruited females drops drastically as they are caught in the fishery. As we showed, if 20 million recruits enter each years fishery, the number of females will drop from 10 million to one million by the end of the season. Thus the ratio of V-notched to total landed lobsters changes continuously and a single sample taken at one point in time is not a good measure with which to calculate abundance.

5. If the gauge is increased we will lose the very important chix market which is the mainstay of the Maine market.

This statement is partially correct in that the number of lobsters marketed as "chix" would indeed fall as the size distribution of landings changed. What it neglects is that there would be substitution of one market for another since fewer chix would be landed but more larger sized lobsters would be landed. What is of importance is how total ex-vessel revenues would change rather than revenues associated with the now dominant size class. Total revenues may go up or down depending upon whether the price decreases necessary to clear the larger-sized markets offset the quantity increases, and whether the price increases which will result as fewer chix are marketed offset the quantity decreases. As will be discussed below, the relationship between total ex-vessel revenues and changes in quantities landed depends on the so-called "elasticity" of demand or its related price "flexibility."

Figure 7: Population distribution after gauge increase.



IV. The State of Knowledge—Lobster Markets

A. Product types, Geographic Range, and Market Structure

There are mainly two types of American lobster product: lobster in the shell (live, freshly cooked, or frozen whole) and lobster meat extracted

from the shell (fresh, frozen, or canned). Lobster in the shell is generally considered the more unique of the two products (lobster meat must compete with many other crustacean meat products) and commands luxury food prices due to the 'reflected glamour' of the in-the-shell product (Pringle et al. 1983). Because of this uniqueness, direct substitutes for in-the-shell lobster are difficult to identify. The New England Fishery Management Council (NEFMC) estimates that 87 percent of the domestic landing is marketed in the shell, either live or freshly cooked, and U.S. Bureau of Census data on imported lobster products indicates that since 1967 the proportion of Canadian imports marketed live in-the-shell has averaged 80 percent by product weight and 64 percent by value.

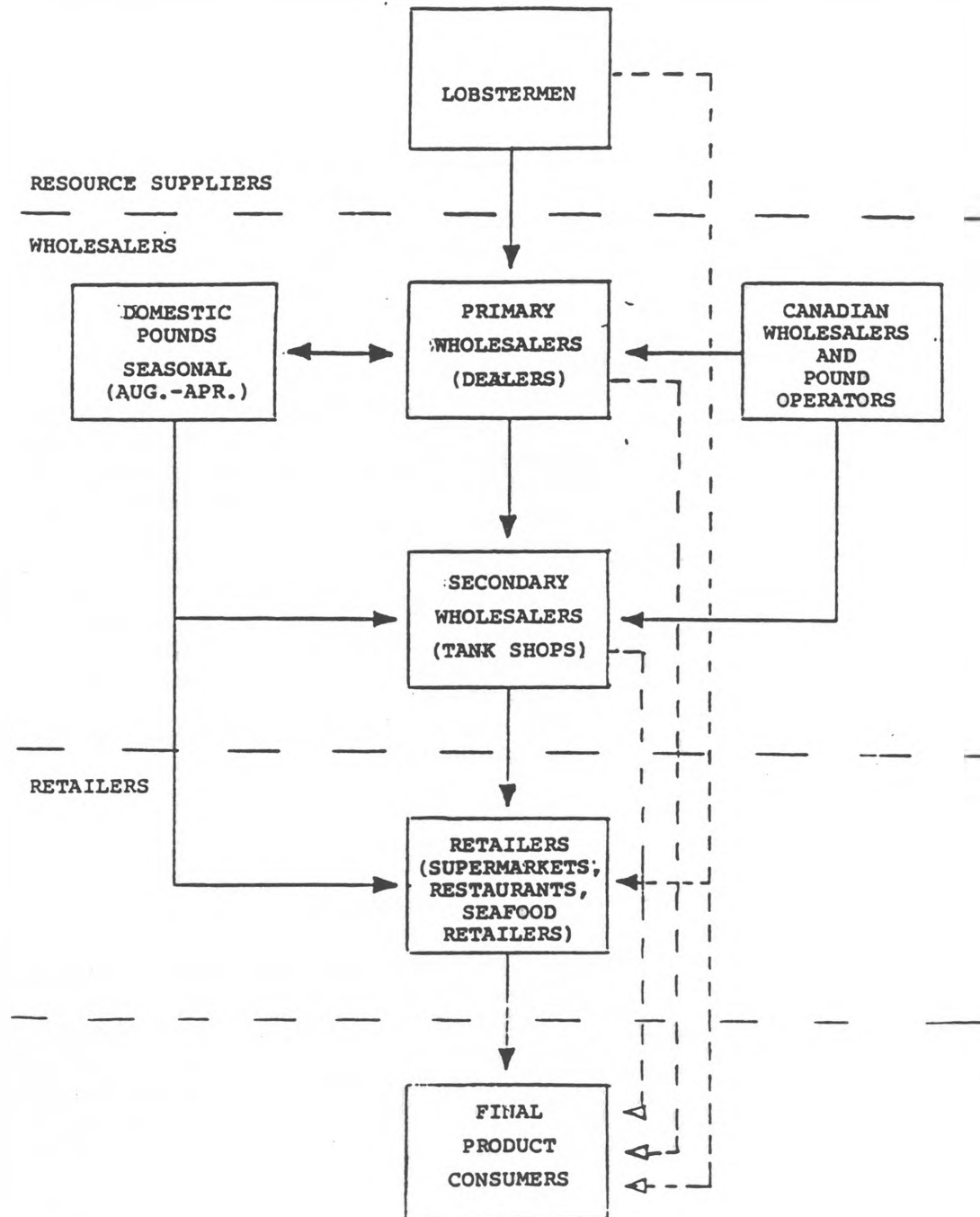
Economic forces at work in the regional live lobster market operate within an organizational framework comprised of successive levels of market demand. First, and nearest the resource base, are the demands of the primary wholesalers, or dealers, for domestic landings at dockside. At a slightly higher level are the demands of secondary wholesalers on primary wholesalers. Ordinarily the demands of primary and secondary wholesalers exceed the limits imposed by the volume of domestic landings and these firms seek live lobster inputs over and above available domestic landings. This results in a wholesalers' demand for live lobsters imported from Canada. Also, because excess supplies of (sometimes inferior quality) live lobsters routinely occur seasonally and most wholesalers do not possess facilities to store substantial quantities of live lobster for extended periods of time, there exists a seasonal demand on wholesalers by pound operators, and subsequently, seasonal demands on pound operators by wholesalers and retailers.

At a higher level are the demands of retailers on wholesalers and finally, there are the demands of the consumer on the retailer. Three major markets arise from this organizational framework: the exvessel landings market, the wholesale market, and the retail markets. In addition, two subsidiary markets, the imports and pound holdings markets, serve to smooth out the U.S. market in periods of peak supply or high demand. The three market levels and the various channels of product flow within and between them are shown schematically in Figure 8.

B. The Nature of Total Live Lobster Supply to U.S. Markets

U.S. and Canadian lobstermen must decide where, when, and how intensively to fish based on factors such as the movement, growth, and general abundance of the lobster stocks, constrained by weather, seasons, and government-imposed harvest regulations. These factors are, in general, independent of the prices lobstermen receive in the short-run (month). This situation results in a supply of lobsters which is subject to wide variations in quantity both within and between years. Hence, regional U.S. live lobster markets, especially those of the first buyers, are 'supply driven' in that variations in supply against a relatively stable demand determine prices. The role of supply variations is moderated in successively higher market levels because U.S. wholesalers and pound operators are not limited to purchasing only domestic landings. They

Figure 8: Lobster product flow.

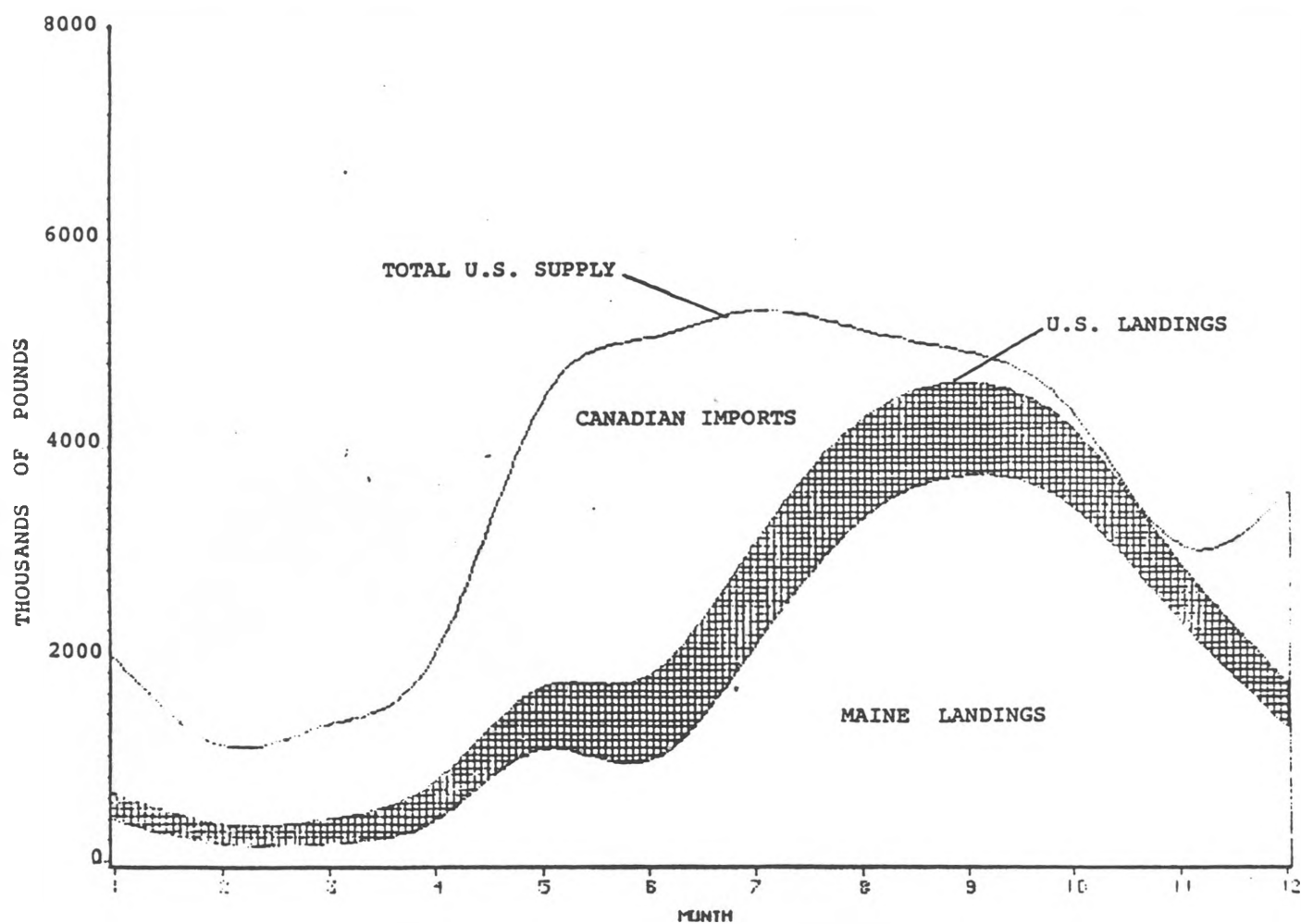


routinely purchase imported lobsters at prices which may be lower or higher (depending on quality) than the prices of comparable domestic lobsters, or they may buy in periods of heavy landings and hold supplies over to periods of relative shortage. In fact, the Maine Import-Export Lobster Dealers Association (MIELDA) estimates that their members handle a volume of imported lobsters equivalent to their total handling of Maine landings. Thus, the total U.S. supply of live lobsters in any month is comprised in varying proportions of lobsters landed domestically that month, lobsters supplied by domestic pound operators, and lobsters imported from Canada. Depending on the season, Canadian imports may be either freshly caught or pound stock.

Landings and import statistics indicate the U.S. supply of live lobsters was about 52.9 million pounds in 1984. Over time the U.S. supply has exhibited a relatively stable and thus predictable seasonal pattern. Figures 9 and 10 show the seasonal variation in supply and the proportion attributable to imports from Canada, landings in Maine, and landings from the remainder of the U.S. lobster producing states, for the period 1967-1984 and for 1984. Because information on domestic pound purchase and sale volumes is not available, the figures probably misrepresent the seasonal timing of at least a fraction of the supply. Live supplies are generally lowest in February, rise gradually through April, increase rapidly in May, and remain at a high level through October. Supplies decline somewhat in November before rising again to a moderately high level in December, and decline again thereafter. As noted previously, the market for imported Canadian lobsters and the extended storage of live lobsters by pound operators are mechanisms that have developed to smooth supply and prices in the U.S. market. The magnitude and timing of Canadian imports, as shown in Figure 9, illustrates how imports are employed to moderate swings in domestic supply. Briefly, the seasonal pattern of the U.S. landing is generally unimodal with a seasonal peak sometime in late summer or early fall. The seasonal pattern of the Maine landing is similar to that of other lobster producing states except that Maine landings reach their peak several months later in the year. In contrast, the seasonal distribution of Canadian imports exhibits a bimodal pattern with a large peak in either May or June (sometimes as late as July) and a subsequent, smaller peak, in December. It is clear that the bulk of Canadian imports arrive just as domestic supplies are coming onto the market and summer demand is growing.

It is now well known that the Canadian government purposely organizes its lobster fishing seasons to avoid gluts on the U.S. market and hence they help maintain price stability. Figure 11 shows the twenty-five Canadian inshore lobster districts and Table 1 gives minimum carapace lengths and the durations of the open seasons which pertain in each district. These seasons ensure that Canadian imports come on the U.S. market when prices are generally higher due to a shortage of domestic landings, and it is for this reason that Canadian imports are said to reduce the potential income of U.S. lobstermen. In addition, Canadian lobsters are generally much more durable for shipment than U.S. lobsters and thus command price premiums because of lower mortality.

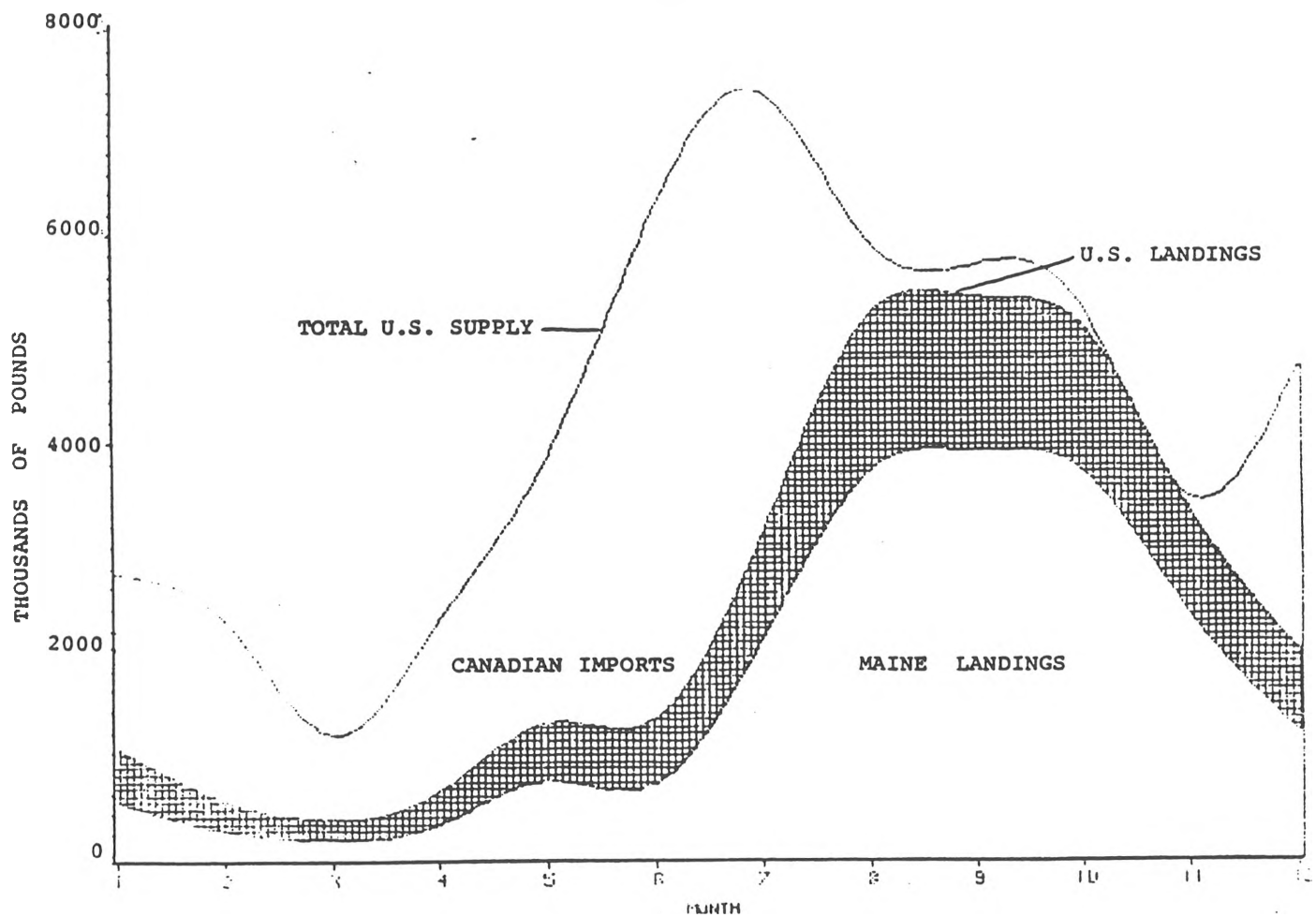
Figure 9: Season variations in lobster supply: average 1967-84.



A final component of U.S. supply so far only briefly discussed is the domestic pound stock. Pound operators possess facilities (usually tidal impoundments or floating lobster cars) for the extended storage of live

lobsters and, depending on market conditions and the season, can together command a substantial portion of available lobster supplies (MIEDLA estimates pound capacity in Maine to be in excess of five million pounds). Pounds serve primarily two market functions: they improve product quality

Figure 10: Season variations in lobster supply: 1984.



and they smooth market supply. Maine pound operators typically purchase pound stock in the fall at low relative prices, either by buying recently molted, inferior quality lobsters (shedders) or lobster supplies in excess of market demands. Since fall is the period of highest domestic landings, pound owners that purchase shedders remove a lower quality product from the market at a particularly opportune time.

Pound operators expect to cover costs and make a profit on the live inventory they sustain since prices routinely advance throughout the winter months due to increased holiday demand and declining supplies. Pound operators sell their stock in wholesale and retail markets gradually during the winter and spring. However, it is common for a price drop to occur sometime during the spring due to rapid increases in the quantity of domestic and imported lobsters on the market. Because the precise timing of this price drop is rarely known with certainty (wholesale and exvessel per pound prices sometime drop in excess of a dollar per week), pound operation is a risky business. Monthly wholesale price data from the Fulton fish market in New York indicates that, since 1967, the spring price drop has occurred equally often in April and May, but in 1977 and 1981 the drop occurred in March.

Figure 11: Canadian lobster harvesting regions.



Table 1: Canadian lobster size regulations.

District number	Minimum legal size (carapace length, cm)	Season
1	8.1 (3-3/16")	2nd Wed. Nov. to Jan. 14 April 1 to June 29
2	8.1 (3-3/16")	2nd Wed. Nov. to 4th Thurs. June
3	8.1 (3-3/16")	October 15 to December 31; March 1 to July 31
4a,b	8.1 (3-3/16")	Last Tuesday in November to May 31
5a,b	8.1 (3-3/16")	April 20 to June 20
6a	8.1 (3-3/16")	May 20 to July 20
6b	6.98 (2-3/4")	May 16 to July 15
7a	8.1 (3-3/16")	May 1 to June 30
7a1	8.1 (3-3/16")	May 10 to July 9
7b,7b1	6.35 (2-1/2")	May 1 to June 30
7c	6.35 (2-1/2")	May 1 to June 30
8	6.35 (2-1/2")	August 10 to October 10
9a	7.6 (3")	May 10 to June 10
9b	-	No open seasons in lagoons
10a	7.6 (3")	May 20 to July 31
10b	7.6 (3")	June 15 to August 15
10c	7.6 (3")	May 10 to July 27
10d	7.6 (3")	May 1 to July 17
11	8.1 (3-3/16")	April 20 to July 5
12	8.1 (3-3/16")	May 5 to July 10
13	8.1 (3-3/16")	April 20 to July 15
14	8.1 (3-3/16")	April 20 to June 30

¹Offshore areas are not indicated in figure . There are currently eight offshore lobster licenses being issued in Canada. Two are restricted to Georges Bank and six are for Georges Bank and southeast Nova Scotia.

Unfortunately, because a time series of data measuring aggregate purchase and sale volumes of Maine pound operators does not exist, no quantitative analysis of the effects that this segment of the industry has upon lobster supply and market price is possible.

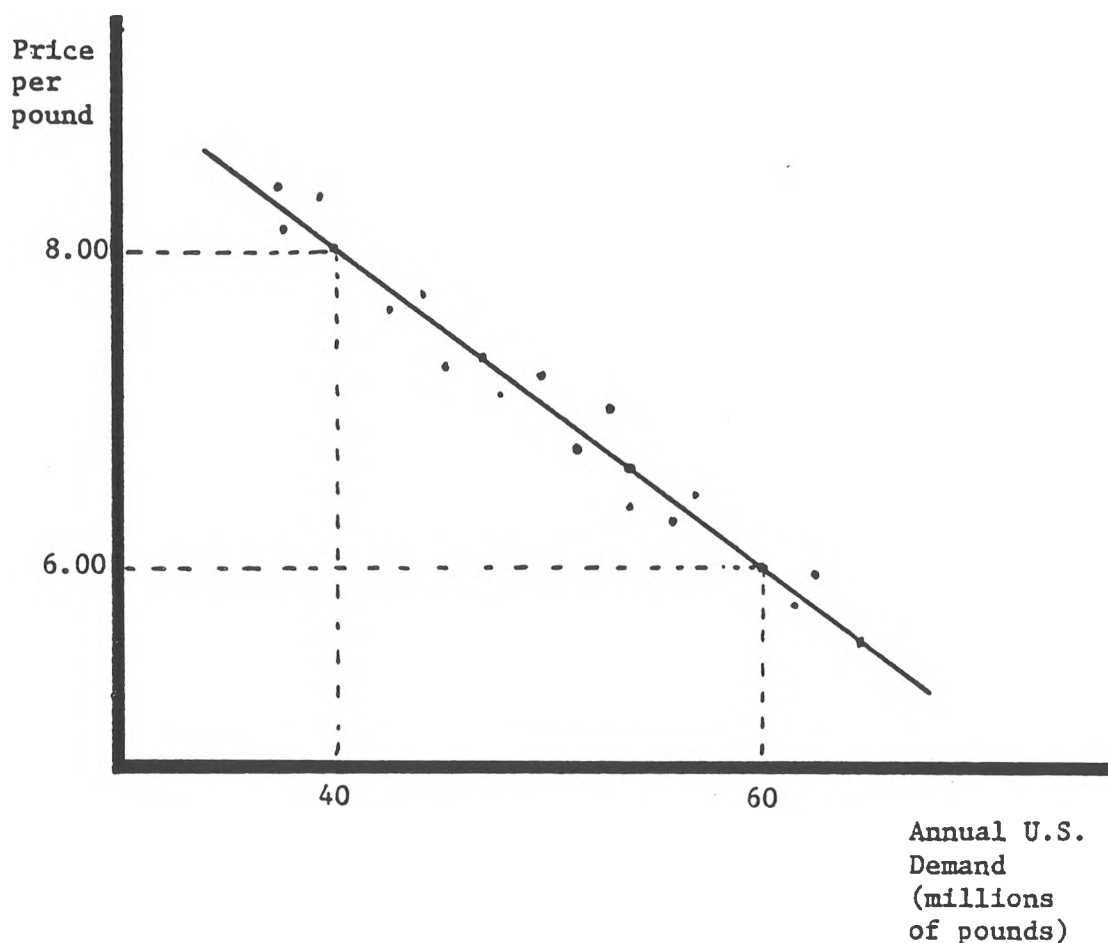
C. The Nature of Live Lobster Demand

One way to view the structure of the U.S. market for live lobsters is as a hierarchy of markets with the markets of the consumer for the final live lobster product providing the ultimate motivation of the entire process. When market structure is viewed in this way, consumer or retail demand is referred to as primary demand and the term "derived demand" is used to refer to demands for lobsters used to "produce" the final product. Thus, both the wholesale demand and the exvessel landings demand are derived demands. Price in derived demand markets differs from those in primary demand markets by the amount of marketing, processing, and handling charges per unit of product. Derived demand can change either because primary demand changes or because marketing margins change. Derived demand relationships can be measured directly using price and quantity data which apply to the appropriate stage of marketing, or indirectly by subtracting margins from the primary demand schedule.

Economists summarize all of the factors which motivate consumers, retailers, wholesalers, and dealers to buy lobsters in what are called demand curves. A demand curve reflects the quantity which will be "demanded" or removed from the particular market at different prices over some time period. Demand curves for all products exhibit what is called the "Law of Demand"; namely, that the lower the price charged, the more will be demanded or taken off the market in a given period. Economists and statisticians gather data on quantities sold in different periods and prices that clear the markets in order to estimate the exact quantitative relationships between prices and quantities marketed. In Figure 12 below we show a hypothetical estimated demand curve and the data points which might have generated it. Note that for observed prices that are relatively high, fewer lobsters are demanded whereas in periods where price is low, more lobsters are marketed.

In estimating demand curves, it is important to account for factors other than prices which may also affect the quantity taken off the market. Economists distinguish between movements along a demand curve (as price changes) and shifts of the demand curve. Shifts in demand (i.e. the same quantity marketed at different prices) occur over time with changes in population size, its distribution by age, the level of income of consumers, etc. as well as due to changes in prices of substitute products (other crustaceans, alternative species of lobster) and seasonal changes in consumer demand (e.g. Christmas, New Years). Thus, for example, the same quantity landed in December may command a much higher price than in October due to a temporary seasonal holiday demand shift. When estimating price/quantity relationships it is important to separate statistically the different effects of movements along a demand curve and shifts of a demand curve.

Figure 12: Hypothetical Demand Curve for Lobsters



The manner in which prices actually get established to clear the market of available lobsters is basically a reflection of the forces of supply and demand. When few lobsters are being landed, their prices are bid up by those buyers who are willing to pay the highest prices. Hence high prices in market data generally correspond to periods of lower landings. Conversely, when lobster is abundant, marketers must cut prices in order to entice more consumers into taking them off the market. The lobster market hierarchy is thus one that is termed "supply driven" in that the timing and quantities of supplies (landings) largely determine how high or low prices will be.

The ultimate total demand for live lobsters in the U.S. market is determined by the retail markets for the commodity. Contacts with wholesalers indicate that restaurants, supermarkets, and specialty seafood shops are the important sellers in the retail market. Within these groups restaurants tend to exhibit the most diversity in terms of retail price and wholesale demand. However, this is due in large part to their differences in proximity to population centers and the variety of services and other

intangible consumer amenities that restaurants provide. Very little retail price data is routinely collected.

While, in general, buyers view all live lobsters as a unique product, lobsters within different size ranges command different per pound prices in virtually all retail markets. The reason for this is that lobsters of different sizes possess different marketing characteristics, and these characteristics determine end use. Examples of marketing characteristics mentioned by wholesalers include how easy a lobster is to eat, its appearance, the meat yield per pound and per lobster, and unit cost. Over time the different end uses have served to segment the overall U.S. live lobster market into several interdependent markets for specific size ranges. These markets are interdependent in the sense that price changes among them caused by changes in the size composition of the overall live lobster supply cause some demanders to substitute consumption of one size for another.

Product classifications, size ranges, and end uses for the size ranges for which we found distinct markets operating are given in Table 2. As indicated, per pound price increases with the size of the lobster until a threshold size of about three pounds is reached. Lobsters above three pounds are said to be too big to serve easily and without waste, and the price per pound decreases somewhat. The premium price paid for select lobsters is probably an indication of both consumer preference for, and the relative scarcity of, lobsters of this size. Legal size limits and the intensity of the fishery determine the range of sizes and volume within each size range available for marketing.

D. Live Lobster Supply Linkages

Over time various supply linkages, or market channels, have evolved to direct the supply of live lobsters from dockside to consumer. Supply linkages tend to establish themselves via an extended series of mutually beneficial transactions between supplies and buyers and function to transfer the live lobster product within and between the exvessel, wholesale, and retail market levels. Although the lines of demarcation among the market levels are not always sharply drawn within firms (some large, vertically integrated firms harvest, wholesale, and retail live lobsters), functionally these markets are distinct. Live lobster supply linkages are strongest in the northeast where lobster markets are well established and active year round.

Supply linkages begin in the exvessel landings market. In 1984 this market provided about 55 percent of the U.S. supply of live lobsters. Sellers in this market are numerous and decentralized fishermen each functioning more or less as an independent owner-operated firm. Buyers are coastal wholesalers who maintain offloading facilities and circulating seawater systems which permit processing and temporary storage of the landing. Processing consists of separating the landings into size ranges commensurate with established end uses and extracting the meat from those lobsters that become weakened or exhibit other characteristics not suitable to the live market.

Table 2: Product types and end uses by size classification.

MARKETING TERM	WEIGHT (lb)	CARAPACE ¹ LENGTH (mm)	WH'S'LE ² PRICE (\$/lb)	RETAIL ³ PRICE (\$/lb)	END USE
chix, chicken	<1.25	81-90	3.60	3.99	twin and triple lobster specials, supermarket loss leaders, chain seafood restaurants, seafood bakes, home consumption
quarters	1.25-1.49	91-96	4.00	4.39	medium priced restaurants, hotels, chain seafood restaurants, seafood bakes, home consumption
halves	1.50-1.99	97-106	5.25	6.99	medium to high priced restaurants, hotels, home consumption
selects, markets	2.00-3.00	107-123	5.90	6.99	highest priced restaurants and hotels, especially those close to population centers and casino gambling, home consumption
jumbos	>3.0	>123	4.50	5.99	processed for meat, specialty 'family style' restaurants, raffle prizes, home consumption
small cull	<1.5	damaged, all sizes		3.49	supermarket loss leaders, home consumption
large cull	>1.5			3.99	

¹ carapace length to weight relationship for Maine lobsters, Thomas (1973).

² Mayflower Seafood Co., Plymouth MA, 11-30-85. High volume wholesaler who sells nationwide.

³ The Lobster Pound, Manomet MA, 11-30-85. Retail outlet operated at wholesale facility of high volume wholesaler who sells primarily on Cape Cod.

It is common for relatively personal, unwritten reciprocal agreements to exist between individual lobstermen and shoreside wholesalers. Factors which form the basis for this form of relationship include the strong preferences of the wholesalers' clients for a reliable and steady supply of lobsters and wholesaler ownership of offloading facilities (Acheson 1985, Wilson 1983). Some wholesalers also provide bait, equipment, and offer relatively favorable short-term financial backing for equipment and repairs, thereby reducing the production costs of those who sell to them.

Primary wholesalers can meet their supply requirements either with lobsters purchased directly from lobstermen or through exchanges with other wholesalers. Because lobsters obtained from other wholesalers are relatively expensive, wholesalers rely heavily on supplies from the exvessel landings market. In this situation, the threat of selling his future landing elsewhere provides lobstermen the leverage required to ensure a 'fair' valuation of their catch.

As Figure 9 indicates, considerable lateral trade is required at the wholesale level to balance live lobster supplies with the demands of retailers. A 1978 nationwide NMFS wholesaler census identified 190 firms which handled American lobster. Coastal wholesalers who purchase large quantities of domestic landings typically sell a portion of their volume directly to retailers, some to secondary or intermediate wholesalers, and some to pound operators. Sales to pounds usually occur during September, October, and November when the supply of domestic landings exceeds market demands. In winter months when domestic landings are at a low point, many coastal wholesalers in Maine and Massachusetts must purchase pound stock or imported Canadian lobsters to hold their year round clients and to supply coastal wholesalers in southern New England who are close to the centers of winter demand.

Until recently, it was common for coastal wholesalers throughout the northeast to ship small quantities of live lobster to order to inland retailers nationwide. Although lobsters are shipped in containers designed especially for this purpose, variability in the physical condition of the lobsters and shipping delays sometimes results in a portion of the live product perishing in transit. This unavoidable mortality kept supply linkages to remote areas weak and uncertain. Today much of the direct sales to inland retailers has been taken over by secondary wholesalers called 'tank shops'. Industry sources indicate that investment in tank shops began about ten years ago and increased substantially during the past five years. Tank shops possess circulating seawater systems capable of maintaining 20-30 thousand pounds of live lobsters and are usually located near population centers remote from the northeast such as Miami, Denver, Dallas, Los Angeles, and San Francisco. In many respects they differ from primary wholesalers only in their proximity to the resource base. The ability to guarantee their retail customers live lobsters has allowed tank shops to capture a portion of the wholesale market, strengthened live lobster supply linkages in remote areas, and expanded the size of the U.S. live lobster market.

As noted above, Maine wholesalers indicate that they handle a volume

of live lobsters twice as large as the Maine landing. Since the NEFMC (1983) asserts that Boston wholesalers control the largest portion of the direct shipment market, a similar situation probably exists in Massachusetts. While most of the volume in excess of domestic landings is lobster imported from Canada, and live lobster supply linkages typically direct product flow north to south and east to west, wholesalers in Maine and Massachusetts do report occasional purchases of live lobsters from firms in New York and New Jersey and occasionally sell lobsters to buyers in Canada.

Canada is the only country which is a net exporter of lobsters and thus plays a dominant role in supplying world markets. Until recently, lobster marketing in Canada consisted of live sales to northeastern wholesalers and canned meat sales to U.S. and other markets. Recent Canadian marketing initiatives have emphasized the uniqueness of the in-the-shell product and focused on distant, luxury trade markets. The value of Canadian exports increased from \$75 million CN in 1978 to \$102 million CN in 1980, with the bulk of this increase coming from the increased value of the in-the-shell products marketed (Pringle et al. 1983). Evidence of the new Canadian marketing effort was also reported to us by wholesalers in Maine and Massachusetts. They described air shipment subsidies provided to Air Canada by the Canadian government which allowed Canadian wholesalers to ship live lobsters anywhere for 25 cents per pound. It seems at least one Canadian wholesaler took advantage of this program by shipping 'short' (2 1/4 inch minimum carapace length) lobsters to tank shops in southwestern states which do not regulate the minimum size of lobsters.

Major supply linkages to the final consumer consist of retail sales by restaurants, supermarkets, and speciality seafood retailers. Although many primary wholesalers in coastal areas operate retail sales counters, most report retail sales to be only one or two percent of volume. Other supply linkages to the retail market include lobsters sold by lobstermen directly to restaurants or to individual consumers in coastal areas, and direct sales to consumers by tank shops and other secondary wholesalers. The relative importance of these linkages is not known.

E. Estimates of Lobster Demand Curves

As the above suggests, all in all, the market for lobsters is competitive on average and prices seem to reflect current or at least recent balances between supply and demand at each level in the market. This occurs because opportunities for arbitrage (making quick money by buying low and selling high) are rapidly taken advantage of--thereby bidding prices that are "too low" up and/or forcing prices that are "too high" down. Generally speaking, a buildup of unwanted inventories by dealers or wholesalers will be met by reducing prices to move the excess. Similarly, if a shortage develops prices will rise as dealers attempt to purchase amounts necessary to satisfy long-standing customers. Because it is important to keep one's eyes open for opportunities to make quick profits, the network of market information is fairly extensive. This implies that on average, prices in large markets like Boston or the Fulton (N.Y.) fish market will not be too

far apart nor will they differ much from similar local markets when transportation costs are accounted for.

A key characteristic important to this study is the precise relationship between prices and quantities landed. As this overview suggests, lobster markets are supply driven and prices essentially move up and down according to whether supplies are relatively scarce or abundant. The degree to which prices move in response to landings changes is especially important. If landings decrease by 10% and prices increase by 10% in response, for example, total revenues will remain unchanged as a result. On the other hand, if a 10% landings decrease causes prices to rise by 20% then total revenues (price times quantity) will increase as landings fall. Similarly, if a 10% landings decrease induces a market price rise of only 5%, then revenues will fall as landings fall. There is thus an important relationship between the magnitude of price changes which occur in response to landings changes which we call price flexibility. Price flexibility refers to the percentage change in market prices induced by a one percent change in landings. A market is said to be "price flexible" if the ratio of induced price change to landings change is greater than one (versus price inflexible). As the examples above suggest, a market's price flexibility is important as summary measure of what will happen to total revenues when landings change. In particular:

if the market is:	price flexible	price inflexible
when landings decrease	total revenues increase	total revenues decrease
when landings increase	total revenues decrease	total revenues increase

$$\text{price flexibility} = \frac{\% \text{ change in price}}{\% \text{ change in landings}}$$

Unfortunately, little work has been done which attempts to systematically examine lobster market price flexibilities in detail. The most recent studies available before this one is by Wang and Kellog (1984), the results of which were used for the New England Fisheries Council Management Plan and the Richardson and Gates (In Press) work. Wang and Kellog used monthly 1967-78 data to estimate an aggregated (i.e. not size-segregated) U.S. wholesale demand curve. Ex-vessel prices were then used to determine how they were related to wholesale prices. Wang and Kellog's work suggests a monthly wholesale price flexibility of about 0.10, implying that a one percent change in landings will induce a 0.10 percent change in monthly wholesale prices. They also estimated a relationship between wholesale and exvessel prices, finding the latter to be roughly 55% of the former. By using the fact that the percentage change in total revenues associated with a percentage change in quantity is equal to one minus the price flexibility we can easily forecast short term revenue impacts of policy changes given the Wang and Kellogg results. In particular (with a

price flexibility coefficient of 0.10) a one percent increase in quantity will induce a 9/10 of one percent increase in wholesale revenue. Since ex-vessel prices tend to be roughly proportional to wholesale prices, the same nine tenths of one percent change will increase ex-vessel revenues by 9/10 of a percent also. Thus available evidence suggests a simple rule of thumb; namely that, in the short run, revenue changes will mirror landings changes almost one for one—i.e. for every percent change in Maine landings, total revenues to wholesalers and fishermen will change in the same direction by about one percent (actually 9/10 of one percent). In our analysis which follows, we present our own estimates of price flexibilities disaggregated by lobster size classes.

V. Policy Making in the Face of Uncertainty

A. Summary--State of Knowledge

As the above sections on lobster biology suggest, there is a considerable body of knowledge about which we can be fairly confident. For lobsters attaining fishable sizes we know a great deal, partly because the fishery "samples" these animals continuously. Evidence is relatively good on growth parameters including growth per molt (both length and weight), weight/length relationships, and molting frequencies for animals in the most commonly harvested size classes. Evidence is also available on reproductive parameters including age at sexual maturity and eggs production as a function of size. There is some uncertainty about the values of these parameters for very large lobsters that are less frequently encountered.

On the other side of the coin, less is known about mortality, migration, and certain population-level measurements. Fishing and natural mortality estimates vary widely and are extremely difficult to measure in fished populations, although some reasonable bounds can be placed on these parameters. With respect to lobster movement, our understanding is not complete but is improving. Recent evidence suggests that most lobsters do migrate a short distance in a pattern that is apparently seasonal. Tagging studies shown that most animals move less than 20 miles but some move longer distances. Generally speaking, larger lobsters appear to move farther, and about 10 to 15 percent move out of the fishery. Likewise there are no estimates of numbers moving into the inshore fishery from Canada or the offshore fishery.

Another important gap in our knowledge is the number of lobsters added to the brood stock with V-notching. While there is good information on numbers notched each year (see Table 3) under DMR auspices, there is no comparable data on numbers notched over past years in the voluntary fishermen's program. There have been several recent cooperative surveys by UMO and the MLA (Daniel et al.) which report sampled V-notched lobsters as a percentage of total landed females. These are valuable first steps, but without knowing the total population abundance of females, it is difficult to estimate the contribution of these reported fractions to total egg production.

Table 3. Weight of lobsters V-notched and released by DMR (average size 2.5 lbs, data from W. Pinkham and J. Krouse, DMR).

	Total lbs	lbs berried
1976	32,896	N/A
1977	22,294	N/A
1978	14,856	N/A
1979	24,374	N/A
1980	32,406	2,929
1981	19,747	14,493
1982	35,368	5,644
1983	60,710	5,162
1984	18,492	N/A
1985	22,298	N/A

A final and important gap in our knowledge of lobster biology is our poor understanding of both the qualitative and quantitative aspects of their pre-recruit lifestages. This is particularly troubling since it means that it is currently impossible to judge whether the current fishery is providing enough eggs to sustain itself at recent levels. There is limited evidence that the system is "forgiving" over some range in the sense that egg production can be reduced without severe repercussions at least up to a threshold. Unfortunately we do not know whether we are at the threshold or not. What we do know is that as exploitation rates have increased (both inshore and offshore) we have pushed the fishery closer to the threshold by reducing egg production.

With respect to economics and markets, there is a reasonable body of both data and analysis available. Markets appear to be quite competitive and distribution channels have evolved to allocate lobsters of different sizes into different end use markets. There is a substantial seasonal pattern to both demand and various sources of supply, and Canadian importations and pound supplies tend to smooth out the irregularities in Maine landings over the year. An important market response parameter is the price flexibility coefficient, or percentage response in market price due to a one percent change in market quantities. What little evidence we have on this parameter applies to the lobster market as a whole and is not segregated by various lobster size classes. Available (aggregate) estimates suggest that the lobster market is price inflexible in that a one percent rise in quantity will induce a less than one percent fall in market price. This

implies that if Maine landings rise, prices will not fall in equal percentages to wash out the gains and hence, total revenues should rise. If landings fall, on the other hand, revenues should fall.

B. Uncertainty and the Role of Modeling

As the above should make abundantly clear, even though we know a lot about lobsters, there is some degree of uncertainty in our understanding of both lobster biology and economics. Some of these aspects of uncertainty might become better understood with more research but other aspects will be much more difficult, or impossible to ever fully understand. In the final analysis, then, it is impossible to eliminate all uncertainty and policy making must be made in the face of some background uncertainties.

There are at least three types of approaches which might be followed given the uncertainty involved. The first is essentially a business-as-usual or status quo policy. In many ways this appears the least painful since the industry has indeed been living with circumstances as they now exist for some time. On the other hand, there is some danger in being lulled into thinking that because the fishery appears stable then it really is stable, or that it will continue to be. As we pointed out earlier, managed fisheries are not static. As lobster values increase, effort and exploitation rates will continue to escalate. Thus even though catch may be constant now, there may be a steady and perhaps unforeseen erosion of the brood stock. If the stock-recruitment relationship is as depicted in Curve B of Figure 1, there will be some warnings of impending fishery declines. These may not be recognized as due to fishing pressure, of course, and instead may be ascribed to normal fluctuations (which have averaged $\pm 20\%$ over the past years). Thus even in the best-case scenario where there may be warnings and potential for corrections, actual actions may only be initiated after some substantial declines in catch and revenues. If the stock-recruitment relationship is like Curve A, in contrast, the future may bring a sudden, unforeseeable and cataclysmic drop in harvests which may be a very severe blow to the industry. This is obviously a much worse possibility and one closer to that forecast by some biologists who warn of possible "collapses" of the fishery.

The importance of this is not so much in outlining details of scenarios but more to caution that a business-as-usual policy is not as innocuous as it may seem. If indeed there are forces at work which are undermining the maintainance of a brood stock, then continuing with the same is tantamount to continuing to undermine the brood stock. Unfortunately there is no way to pin down with certainty where we are in terms of "stock safety" or even what mechanisms link the brood stock to subsequent recruitment. One can be reasonably certain that there will come a day where egg production is insufficient to sustain the fishery if measures are not taken to maintain egg production in the face of increasing fishing pressure.

This points to at least one possible justification for the status quo position and that is to regard current policies and continuing with the status quo as an "experiment". Since many believe that there is no problem

with the status quo, the fishery could be carefully monitored as effort intensifies in order to find out just how far it can be "pushed" without collapsing. This would give scientists and the industry a better future knowledge of just what happens prior to and during a collapse, what factors may forewarn of the collapse, and how long it takes the fishery to recovery. The problem of course, is that the industry must suffer the collapse in order to understand the mechanics of it.

The second type of approach to current uncertainty is to do nothing as direct policy but initiate research to narrow the bounds of uncertainty. As discussed above, there are critical gaps regarding mortality, stock-recruitment relationships, migration, inshore/offshore interaction, and quantitative relationships between markets for different sized lobsters. Some of these could be better understood with some concerted efforts supported by research funding.

The danger in this option is that it may also lull us into a false sense of security for at least two reasons. The first is that the dynamics alluded to earlier will continue as research is being designed and undertaken. Good studies will take several years and results will only become credible and accepted after even more years pass. It is unlikely, in fact, that much of the particularly critical gaps in biological understanding can be filled in less than 10-15 years. Thus there is the danger that the fishery will fail before critical information can be gathered. The second problem with putting all faith in more science is that the unfortunate fact is that we can never eliminate all uncertainty. Scientific studies do not come up with definitive numbers, rates, or process descriptions but rather they yield ranges over which we can expect certain numbers to vary. Thus we will never be able to say, for example, that all lobsters over 4 1/2 inches migrate to offshore waters. What we may conclude, instead, is that, on average, a given lobster tends to migrate towards the offshore area when it reaches a size range of 4 to 5 inches and that many lobsters do not seem to follow this pattern. This is just a hypothetical example, of course, but the fact is we will still be left with grey areas of knowledge—even after extensive study. The value of research is that it reduces the size of the grey areas and increases the likelihood (not the certainty) that we can make some predictions with accuracy.

A third approach is basically to accept and account for uncertainty present in the system and attempt to do the best we can, given this amount of irreducible uncertainty. This is, in fact, the "modern" approach advocated by many of the more prominent fisheries management experts with both academic and real world experiences. The basic idea is to assemble all of the opinions about "facts" that are of critical importance—spanning research studies by biologists and informed opinion of those in the business. (This has been the intention of this study, of course). Next, some consensus must be reached over what we "know." This, ideally, should involve industry and scientists since both parties can benefit from feedback. Industry, on the one hand, needs to understand where scientifically-determined numbers come from. Scientists, on the other hand, need to understand when and why the scientific data doesn't "feel right" or square with what lobstermen think they observe in the real world. It has

often been the case that scientific studies have benefited (and even required redesign) from the insiders' information that lobstermen possess. Once some acceptable "facts" are determined as the "best that we know," these should be combined and put together in some way to help prejudge the outcomes of various policy options. Practically speaking, given the complexity of this system, the only way to combine facts is with a biological/economic model. Those "facts" which are controversial and for which widely differing opinions exist may be treated separately over the range of reasonable opinion. Thus if fishermen believe, for example, that all or a majority of lobsters over a certain size migrate into New Hampshire waters and are caught there, and lobster biologists believe that the fraction is small, the two assumptions of question can both be tried to see if it really matters to the conclusions of an analysis. Often, diametrically opposed beliefs about certain aspects of complex systems "cancel out" so that it is not worth wasting either breath or research funds on certain controversies.

In the following sections we present results of our attempts to develop such a policy model. It should be noted from the outset that our results are intended to guide people in achieving some consensus over what ought to be done rather than answer for them what should be done. In the final analysis, a model is only as good as what is put into it and in view of the importance of these policy decisions it seems essential that everyone understands and believes in the "facts" that are embedded in the model.

C. Lobster Population Models--Previous Studies

There are numerous existing studies which address some of the issues pertinent to Maine lobster policy options. There are, for example, several studies which examine the effects of various management options on stocks outside of Maine. Although these results are not quantitatively comparable because of different biological parameters, the qualitative results are of some importance. For example, Bennett and Edwards (1981) examine the effect of gauge increases and berried female protection in the European lobster. Saila and Flowers (1968) also examined the effects of protecting berried lobsters and the upper size limit for New England stocks. Campbell (1985, in Press) examines upper and lower size limits, changes in effort, and berried protection on Bay of Fundy stocks in terms of both yield impacts and egg production. Ennis (1985) also examines impacts of gauge increases and reduced effort on egg production and yield of Newfoundland stocks. Fogarty (1980) reports results of changes in effort and lower size limits on long term yield for the New England stocks as a whole as well as the offshore stocks (Fogarty et al. (1982)). Richardson and Gates (in press) also analyze short and long term yield changes associated with gauge and effort changes for a composite of New England inshore stocks and the offshore stock.

Each of the above studies addresses the long term yield impacts of gauge increases and each reaches the same conclusion; namely that long term yield (in pounds) will increase with any of the currently-contemplated proposals to increase the gauge. Of equal importance is what happens during

the transition to the long term equilibrium and here, too, of those studies which address the issue the results are consistent; namely a short term yield decline at first as previously-legal lobsters are no longer available to be caught.

Analyses of Maine stocks specifically can be found in Acheson and Reidman (1982), the Fishery Management Plan, and Thomas et al. (1983). Acheson and Reidman computed the long term effect on yield (weight) of increasing the gauge to 3 1/2 inches in staged increments of 1/16 inch. They predicted a long term yield increase of 7.9% and a short term yield loss of 9.2% in the first year. As they pointed out, whether this policy is "worth it" to the industry is similar to deciding whether an "investment" which involves short term sacrifice and then long term gains is worth it. This can be analyzed by various methods including the calculation of a "rate of return" on the first year "investment costs." The Fisheries Management Plan analyzes a gauge increase to 3 1/4" and predicts a long term gain of 4.6% with an associated first year "cost" of 16% yield loss. DMR computations (Thomas et. al 1983) predict a gauge increase from 81 to 83 mm would result in a 2% gain in the long term with an associated first year loss of 5%.

These result are difficult to compare directly because of differences in units and methods and policies examined. However, given that 1/16 of an inch is 1.6 mm, it is at least apparent that the impacts projected by Thomas are lower than those projected in the FMP plan. The table below compares all of these results with some direct measurements taken by lobstermen and dealers last year (letter from L.F. Sewall to S. Appolonio, March 21, 1985 and letter to W. Atwood from J. Krouse, June 11, 1985).

Study (gauge size)	Long term Change	Short Term Change (1/16 inch change)
Acheson/Reidman (3 1/2")	+7.9%	-9.2%
FMP (3 1/4"	+4.6%	-16.0%
DMR (3 1/4")	+2.0%	- 5.0%
Sewall (3 1/4")	—	-12.1%
Krouse/Attwood (3 1/4")	—	- 8.0%

There has been very little analyses of berried female protection and no population modeling of the potential impacts of V-notching. What little analysis there is of berried female protection suggests the obvious; namely that yield is decreased somewhat and egg production is increased. With respect to V-notching the only data that has been collected is reported in Daniel et al. (LRW). This data was collected in October in a voluntary survey conducted with lobstermen and the reported mean ratio of V-notched

females to females caught is 0.28. The reported sex ratio is 0.58, females to males. It should be noted that this data is preliminary and, as it stands, does not lead to any conclusions about the population impact of V-notching. For example, the female to male ratio is a result of both berried female protection and V-notching and hence is not evidence that V-notching alone is a major factor. In addition, the result that 28% of the females caught are V-notched does not tell us how many females are V-notched. V-notched. In the final analysis, since we really don't know how many V-notched females we have, we cannot conclude much about the role of V-notching without utilizing a population model which sorts out the effects on catch and egg production. For this reason, we turn now to estimates of potential impacts predicted in our modeling effort.

D. Model Description

In this section we describe the specific features we have included in our model of the Maine lobster fishery. As discussed earlier, although others have developed models which give some insight into some Maine policy options, no one has put together a comprehensive model specifically designed to look at Maine problems with Maine specific parameters. In addition, most other approaches are less specific in the sense that more details have been omitted or incompletely included.

Our model has been designed to be flexible in order to analyze, in considerable detail, a range of policy options including V-notching and carapace length changes. The model employs parameters appropriate to the Maine inshore population and the output includes numbers, average length and weight, and total pounds in all size classes from 81 mm upwards (in 1 mm increments). The model also employs the more realistic discrete molting mechanism discussed earlier (as opposed to continuous growth assumptions). Recent data by Campbell (1985) is used to model molt increments and fraction molting annually and these are combined with intra-annual molting schedules taken from Krouse (1973) in order to determine size distributions monthly. Maturity ogives based on data from Krouse (1973) are utilized to forecast reproductive maturity. These are combined with fecundity data from Campbell and Robinson (1983) to determine total egg production. Females are assumed to molt every other year after they become mature.

The nominal value assumed for instantaneous natural mortality is 0.15 (equivalent to a 14% annual mortality rate) with additional analyses conducted at different values. The distribution of fishing effort is over the year is based on data from Thomas et. al (1983) and the model is capable of employing any specified annual fishing mortality rate and any upper and lower size limits over any specified time schedule. The model can also compute the effects of V-notching on population abundance, yield and egg production. Any specified fraction of the berried females that are caught in traps can be V-notched and returned to the population. Separate data arrays are retained for males, females without eggs, berried females, and V-notched females. Finally, the model is "fully dynamic" in the sense that it tracks both the long run equilibrium and the transition to that equilibrium over the short run. This is in contrast to most other approaches which

attempt to focus on the "long run" and the "first year" impacts.

In addition to the basic biological model, we have also developed a comprehensive marketing or price forecasting model. As discussed earlier, the most recent work on lobster price modeling is aggregated across all sizes classes. Since we are interested in examining policies which will change relative numbers in different size classes, we have developed a system of price forecasting equations which is size-specific. In the results presented here we utilize five size classes as follows:

	<u>Size Class</u>				
	1	2	3	4	5
	less than	at least	at least	at least	2 or
range	1 1/8	1 1/8	1 1/4	1 1/2	greater
in					
pounds		less than	less than	less than	
		1 1/4	1 1/2	2	
corresponding	81-86 mm	87-90 mm	91-96 mm	97-106	107 +
lengths	3 3/16" -	3 7/16" -	3 10/16" -	3 13/16" -	4 3/16" -
	3 3/8"	3 9/16"	3 3/4"	4 1/8"	5"

Wholesale price data was gathered for each of these size classes and separate equations were estimated to predict size specific prices per pound. (See Appendix 3). This disaggregation represents a necessary improvement over the more recent aggregated work utilized in the FMP.

E. Model Results—Overall Yield and Egg Production

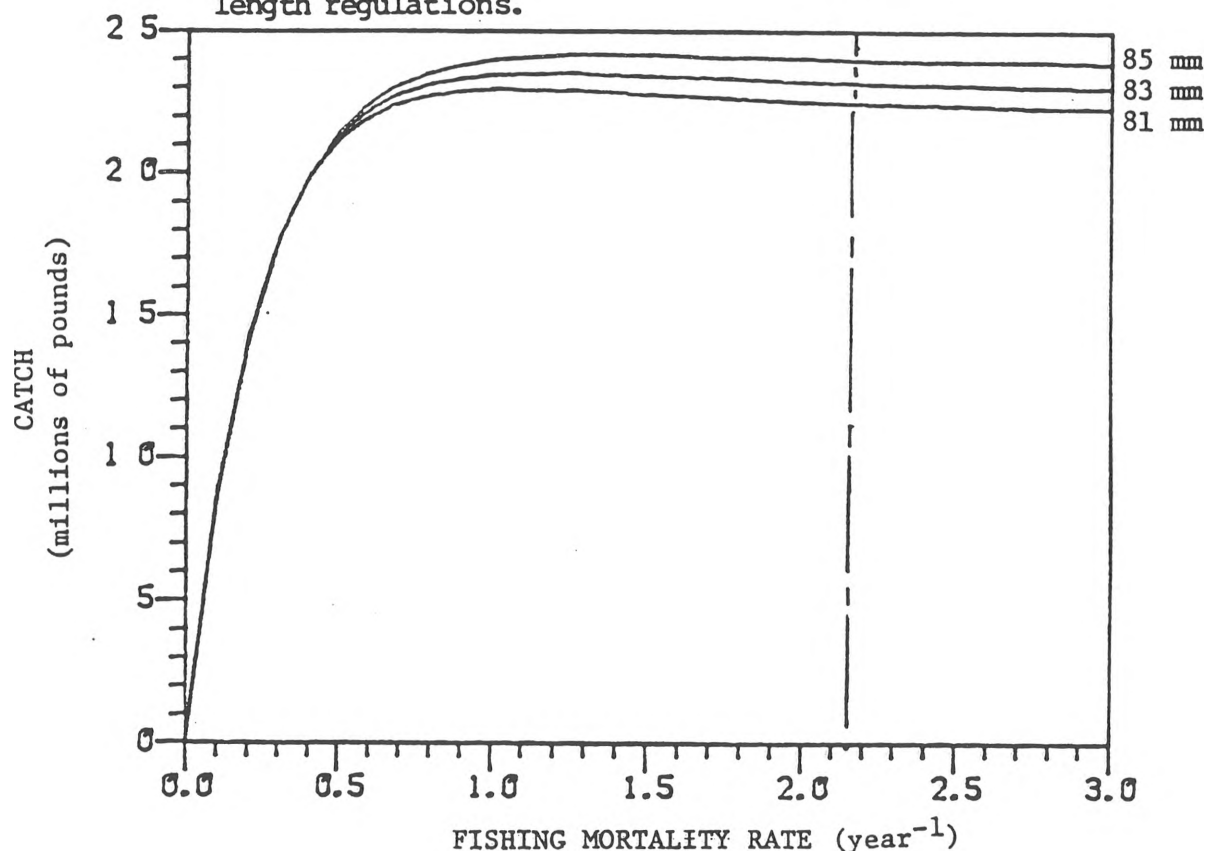
As discussed earlier, there are several important issues to be considered when evaluating various policy options. The first of these is the impact on catch in the fishery. This may be evaluated in terms of total yield in pounds or in economic terms by accounting for the impacts of changes in supply on price. Harvest and revenue changes may be further broken down into short and long term effects. The second issue of importance is stock safety. As discussed above, we do not really know how close we are to the point of which further decreases in egg production will lead to a decline in recruitment. We also do not know how many new recruits will be produced by a given number of eggs. The one thing that we can be reasonably sure of is that an increase in egg production will lead to a safer population. In what follows below, therefore, we evaluate the various options both in terms of their yield (or revenue) impacts and their egg production impacts. Annual eggs production can be considered an index of "stock safety."

Since the Maine fishery is primarily on inshore stocks, we, insofar as possible, use biological parameters that correspond to the inshore

population. We also, however, evaluate the potential impact to the inshore population of permanent migration of lobsters to other (offshore, New Hampshire) stocks. In all cases, our baseline case for comparison purposes assumes a 3 3/16 inch lower limit, a 5 inch upper limit, and protection of berried females.

Figure 13 shows the impact on total long term yield associated with various levels of fishing mortality and several minimum carapace lengths. Under the assumptions that recruitment will remain constant, we can expect that (at current effort levels associated with instantaneous fishing mortality rates of 2.15) long term yield in total pounds will increase by about 6.8% for a gauge increase to 85 mm (about 3 5/16"). The gain in egg

Figure 13: Equilibrium yields associated with various minimum carapace length regulations.



production from this carapace length increase is given in Figure 14. Note first that current egg production is less than one percent of its value with no fishing ($F=0.0$). From this graph we see that a gauge increase to 85 mm (about 3 5/16 inches) would approximately double egg production, thus moving the stock to a safer level.

On the face of it a gauge increase appears like a policy promising a "free lunch" in that more yield is achieved and more eggs are produced thus making the fishery safer. Unfortunately, of course, there is no absolutely free lunch in that in order to achieve these long term gains some short-term

sacrifices need to be taken. These have not been analyzed in detail before because most models have not been able to account for all of the transition dynamics. In Figure 15, we show a few of the possible scenarios. It is possible, after all, to choose a transitional path in order to spread its sacrifice over a period of time. The basic conclusions to be derived for Figure 15 are several. First, the sooner the sacrifice is made the sooner the rewards accrue. For example, if a once and for all increase in the gauge is made from 81 to 83 mm, there will be a one year yield decline of about 8% followed by yield rising in the second year to approximately the pre-change policy level. Thereafter yield will steadily increase to its eventual long term position of about +3% after five years. If it were deemed desirable to get to 85 mm, this could also be done at once or in stages. Doing it in stages avoids the sudden first-year production drop, at the expense of holding production down over a longer period (e.g. 2 years instead of 1) and attaining the equilibrium later (e.g. 6 years vs. 5). These paths are only illustrative of the virtually unlimited numbers of time paths which could be chosen.

Other policy options can also be compared in terms of their effect on catch and egg production. In Table 4 we compare the case without the upper size limit to the baseline (81 mm lower limit, 127 mm upper limit, no V-notching) and the two lower gauge increases discussed above. Removal of the upper limit would reduce egg production to 70 percent of its former level, with a gain of only 0.2 percent in catch. This can be compared to gauge increases to 83 mm and 85 mm which both increase catch a greater amount and increase egg production a greater amount.

Table 4: Long term yield and egg production associated with Maine lobster policy options.

	Lower limit (mm)	Upper limit (mm)	Catch (millions of pounds)	Total Annual Egg Production (billions)
Baseline	81	127	22.46	5.5
No upper limit	81	—	22.51	3.8
Increased Gauge	83	127	23.19	7.4
	85	127	23.98	10.3

Various levels of V-notching can also be compared in terms of their effect on egg production and catch. These comparisons are made in Table 5 for various assumed levels of V-notching (i.e. fraction of trapped females that are V-notched and returned). V-notching has the potential for contributing substantially to egg production at a low cost in terms of reduced catch. The problem faced in evaluating the current situation in

Figure 14: Egg production associated with various minimum size regulations.

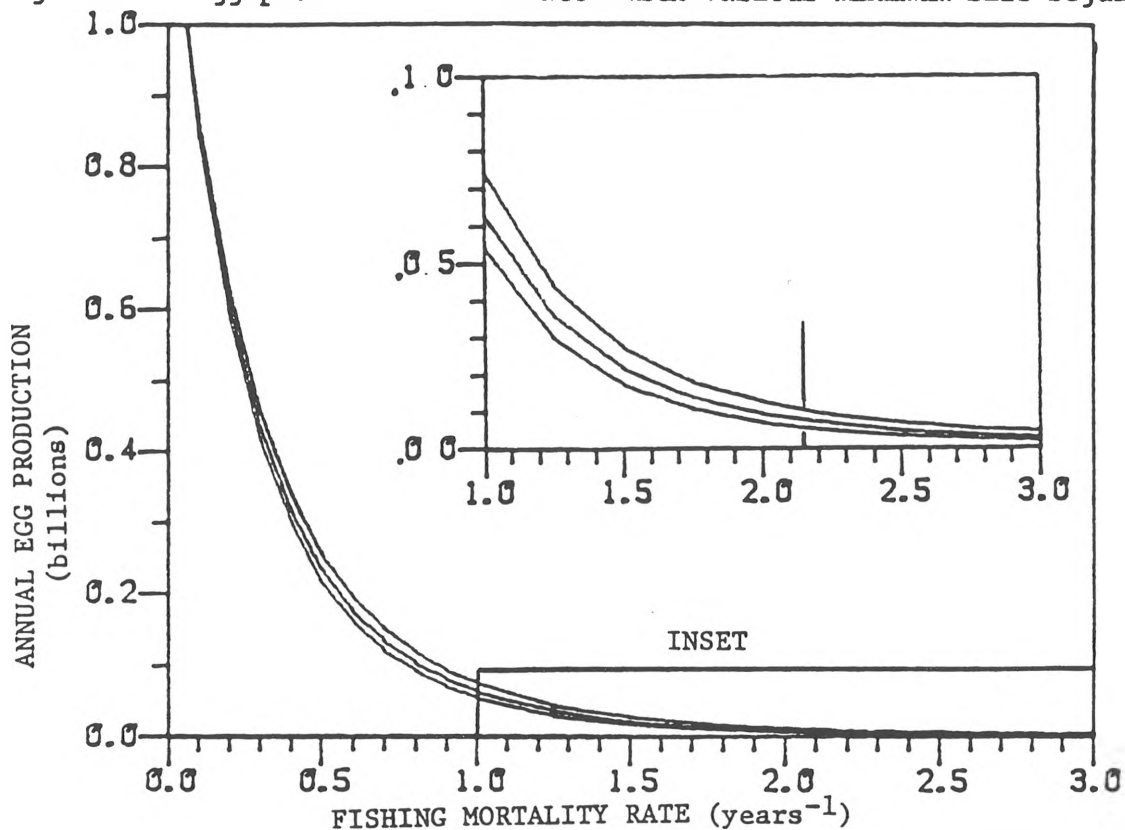
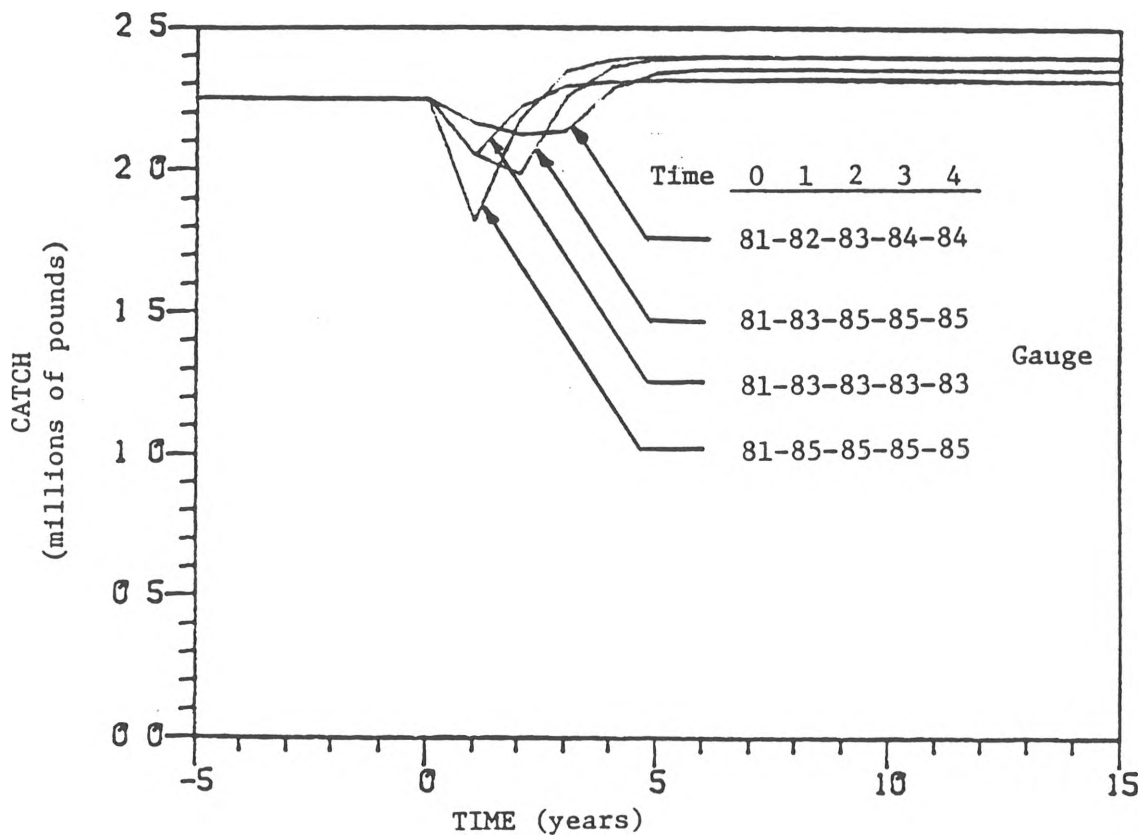


Figure 15. Catch in each year as the lower gauge is increased in various ways.



Maine is that the population of berried females that are V-notched is unknown. If we assume for the sake of comparison, that one out of every four un-notched berried females that is caught gets V-notched every year, then total egg production will be more than doubled for only a slight decline in catch. Another informative comparison is that a V-notching rate of 15 percent is required to equal the egg production of a gauge increase to 85 mm.

Also listed in Table 5 is the predicted percentage of females caught in October that would be V-notched. This percentage can be directly compared to the result from the cooperative V-notch survey that 28% are V-notched. At a notching rate of one in four berried females only 5.7% of captured females are predicted to be V-notched. Even if it is assumed that all berried females that are captured are V-notched, the model (which is based on current knowledge of the fishery and lobster biology) predicts a lower value than the survey results. This inconsistency is further indicative that more study of the effect of V-notching is needed.

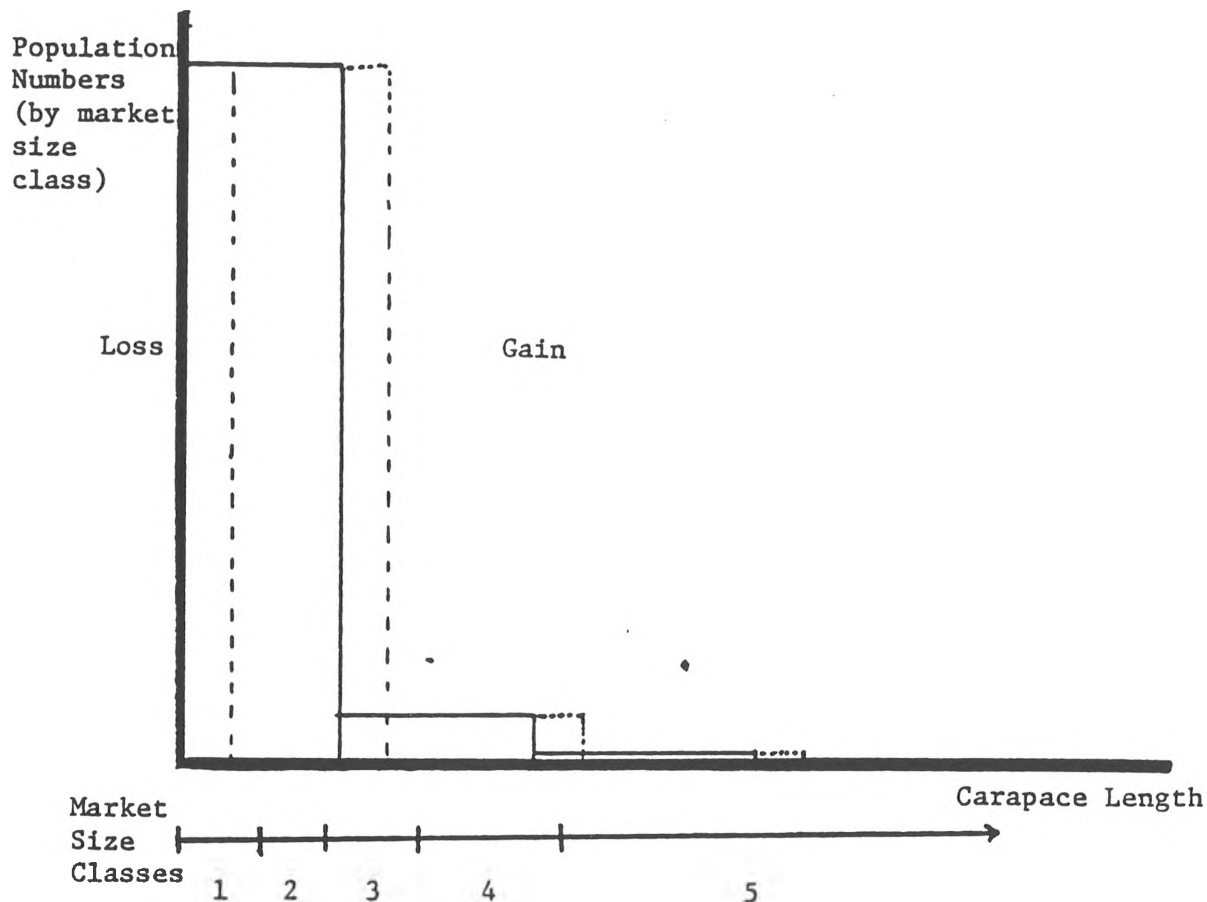
Table 5. The effects of V-notching of various fractions of berried females caught. Figures assume current management.

Fraction of Berried females V-notched and returned	Catch (millions of pounds)	Total Egg Production (billion)	Percentage females caught in October that are V-notched
0.00	22.46	5.53	0.0
0.05	22.45	7.35	1.3
0.10	22.44	9.04	2.6
0.15	22.42	10.61	3.7
0.20	22.40	12.06	4.7
0.25	22.39	13.41	5.7
0.5	22.33	18.8	9.3
1.0	22.26	25.2	13.3

F. Yield Impacts—Detailed Analysis by Size Class

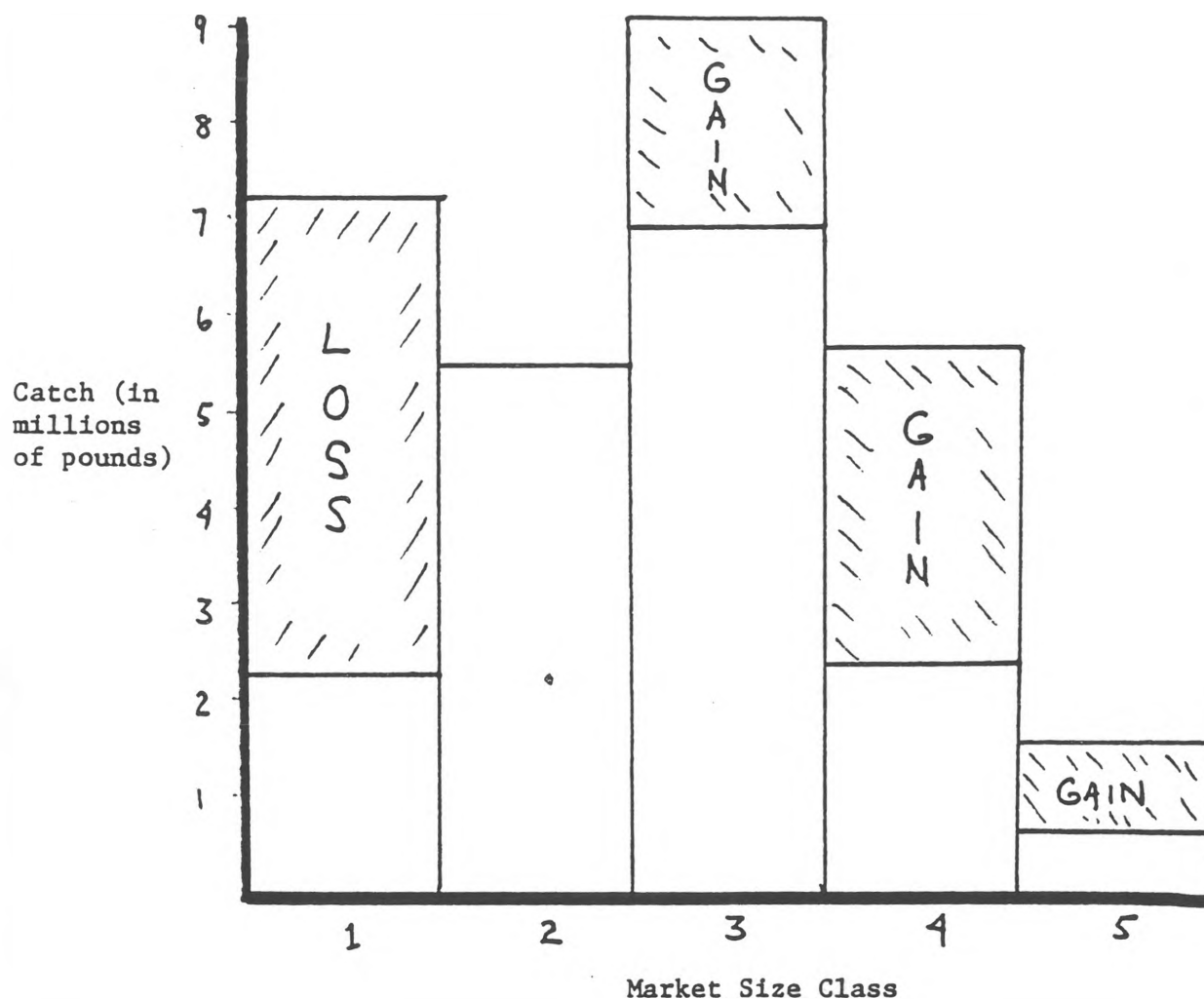
In order to get a better feel for the market impacts of policies such as gauge increases, it is necessary to estimate how the size distribution of catch will change, both in the long run and over the transition period. No other studies have addressed this and it is an area about which it is difficult to hazard even educated guesses. It is possible to hypothesize what would happen, however, by redrawing a diagram earlier presented with a hypothetical carapace length increase of (for example) $3 \frac{3}{16}$ to $3 \frac{5}{16}$. In Figure 16, it can be seen that this hypothetical gauge increase affects.

Figure 16: Size specific long term impacts of gauge increases.



size classes 1 and 3 particularly (i.e. "chix" less than 1 1/8 pounds and "quarters" between 1 1/4 and 1 1/2 pounds). Since the steps simply shift right by 2/16 inches, the chix category will be reduced in poundage but the quarters category will be correspondingly increased. Class 2 will be unaffected and there will be increases in classes 4 and 5. Figure 17 shows long term yields under the current regulations and after hypothetical change to 85 mm (about 3/16 inches). As can be seen, long term yields change as follows compared with base case values:

Figure 17: Size specific long term yield changes associated with gauge increase to 85 mm.



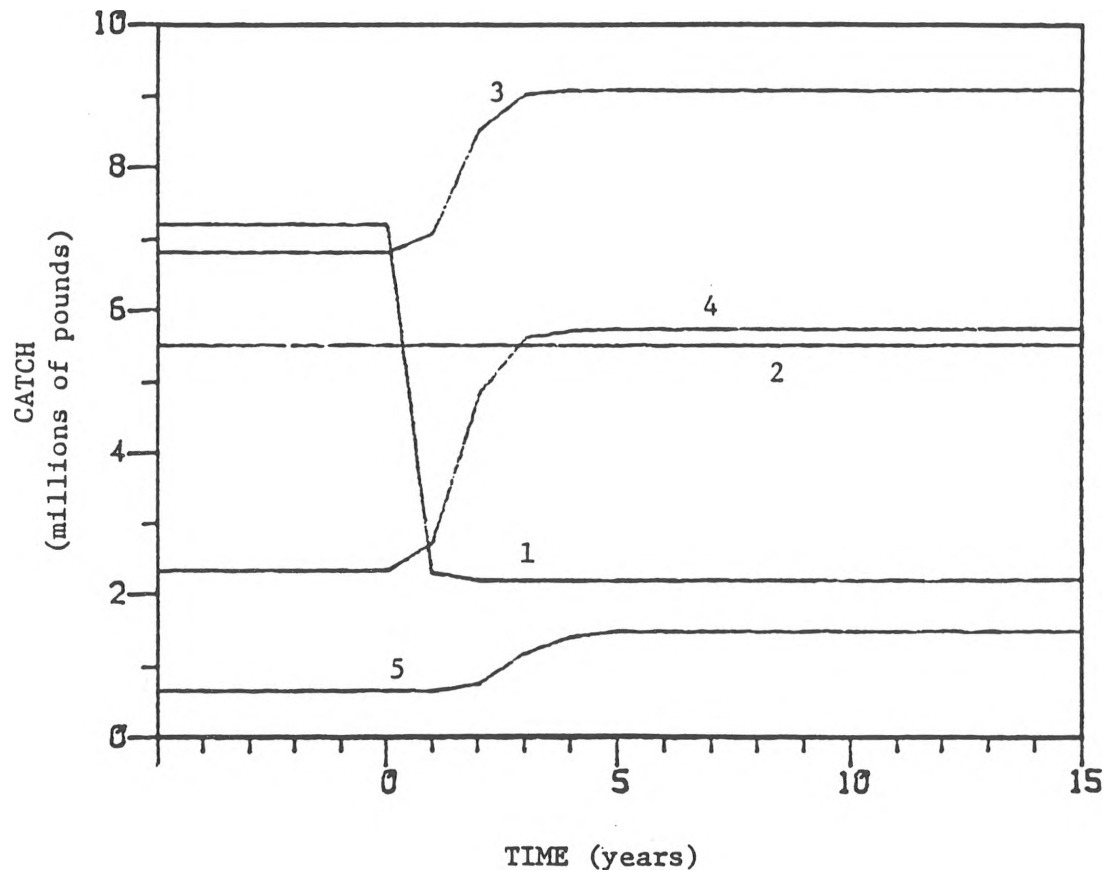
Annual Harvest in Million Pounds

	1	2	3	4	5
81 mm (3 3/16") (equilibrium)	7.21	5.51	6.80	2.33	0.65
85 mm (3 3/8") (equilibrium)	2.20	5.51	9.09	5.74	1.48
% change (in equilibrium)	(-69.5%)	(0%)	(+33.7%)	(+147.4%)	(+127.7%)

Note that even though class 1 yield drops substantially, this is more than made up for in increases in size classes 3-5.

The manner in which the relative amounts change in each category during transition to the long term depends upon how fast the adjustment is made. If a gauge change to 85 mm is made in 1 step then Figure 18

Figure 18: Size specific transition dynamics associated with gauge increase to 85 mm.



shows what would happen. As can be seen, the quantity in size class 1 (chix) falls during the first year—effectively absorbing all of the sacrifice. Thereafter, the system moves towards its long run equilibrium with increases in size classes 3, 4, and 5. Note the substantial increases in the generally higher-priced sizes. Again, these are intended to be illustrative of the possibilities—other scenarios both in terms of final numbers and in terms of adjustment paths are possible.

G. Revenue Impacts

Translating yield impacts into revenue impacts requires price forecasting equations which estimate how prices per pound will respond to changes in quantities marketed. As we discussed earlier, market channels have evolved to supply different sized lobsters to different markets. Each

of these markets is fairly competitive so that prices should be expected to respond in individual markets as relative supplies change. It is not clear, however, how overall revenues would change as quantities in one market went down but were compensated for by rising quantities in another.

In order to evaluate price changes and corresponding revenue changes, we can use our size-specific price equations discussed above. Our price equation estimations give us ranges of "price flexibility coefficients" for each market. Price flexibility coefficients measure the percentage change that can be expected in a given price when quantities in that market change by one percent. In carrying out our analysis we lumped size classes 1 and 2 together after discussing interrelationships between these two markets with dealers. Our estimates are as follows:

Estimated Price Flexibilities				
	Size Class			
	1 & 2	3	4	5
Short Run	-.008954	-.007339	-.00526	-.00382
Long run	-.1420	-.1172	-.00835	-.00562
Total Long Run Revenue Elasticity	+.858	+.887	+.992	+.994

These can be interpreted as follows: for a one percent increase in quantities marketed as chix or "eights" (size class 1 or 2), wholesale prices will fall by .008954 percent in the short run. If the numbers in size class 5 rise by one percent, prices of these (per pound) will fall by 0.00382 percent in the short run. Basically, for brief (e.g. month to month) "blips" in quantities marketed, prices change almost imperceptibly. In the long run, however, for every one percent change in long run numbers in sizes 1 or 2, prices will change by -.1420 percent. Similarly, if the number in size class 3 rises permanently, there will be a percent decrease in prices in that class of .1172 percent per one percent quantity change. Since these percentage price responses per percentage quantity changes are still relatively small in the long run, revenue changes will be roughly proportional to quantity changes. The last row gives the estimated percentage changes in wholesale revenues per one percent change in quantities in each size class. As can be seen, every one percent change in quantities marketed in size classes 1 & 2, 3, 4, and 5 yields 0.858, 0.887, 0.992, and 0.994 percent changes in long term revenues respectively — roughly proportional responses. There is, in fact, extra gain associated with altering the distribution towards larger sizes since a one percent reduction in class 1 & 2 causes losses of 0.852 percent in revenue whereas a one percent increase added to class 3 yields a 0.887 percent increase.

For the long run changes shown in Figure 15, we can predict the

following percentage change in revenues:

	Size Class				
	1 & 2	3	4	5	Total
Pre-change yield (millions of pounds)	12.72	6.80	2.33	0.65	22.50
post-change yield	7.71	9.09	5.74	1.48	24.01
% change in yield	-39.4	+33.7	+146.4	+127.7	+6.8
% change in long term revenues	-33.8	+29.9	+145.2	+126.9	+12.27

H. Sensitivity Analysis

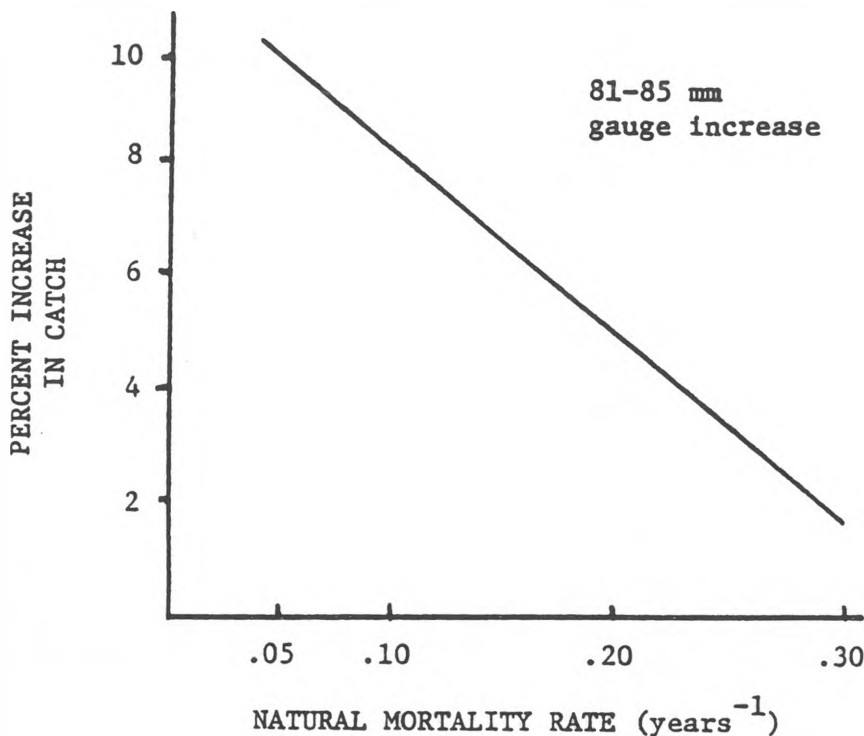
1. Mortality rates

As discussed in our review of the state of scientific knowledge, an important but poorly known parameter is the natural mortality rate. To examine how the model projections regarding catch and egg production are affected by different values of this parameter, we conducted several "sensitivity" tests to gauge its role. For the policy option of increasing the gauge from 81 to 85 mm, our projected long term yield increase with a natural mortality rate of 0.15 was +6.8%. If the value is actually 0.20, this yield gain is cut to 4.8%. For a gauge increase of only 2 mm, each of these numbers would be halved. This sensitivity is shown in Figure 19 and the results are essentially the same with V-notching and an upper size limit. Both egg production and short term losses in the period following a gauge increase are relatively insensitive to the value of natural mortality. The results regarding changes in catch and egg production are insensitive to the actual value used for the fishing mortality rate. The reason for this can be seen by noting that in Figures 13 and 14, the catch and egg production curves are relatively flat for fishing mortality rates near 2.0 (i.e. catch doesn't change with the fishing rate).

2. Growth rates

Although there is less uncertainty about growth rate estimates, it is worthwhile to test their roles in model projections of catch and egg production as well. The growth process we have used may involve inaccuracies either in the assumed fractions molting annually or the increase in size per molt. For example, if the fraction molting annually is really only 90 percent of the numbers we used, the long term yield increase associated with a gauge change to 85 mm will be 6.5% instead of 6.8%. If the molt increment is similarly less than the figure we used (13 percent instead of 15%), then the long term yield gain will be 5.9% instead of 6.8%.

Figure 19: Long term yield gain sensitivity to natural mortality estimates.



Overall, then, our results on long term equilibrium yield changes are relatively insensitive to values used in the growth relationships.

Short term losses, on the other hand, are quite sensitive to growth parameters. This occurs because the loss in first year yield is the fraction of the formerly harvestable range of sizes (81 mm to 93 mm) that is no longer available to harvest (e.g. 81 to 85 mm if the gauge is increased). This fraction depends on the length of the harvestable range, which is basically the increase in size per molt. Thus if the modeled value of the molt increment is larger than the actual value, the actual decline following a gauge increase will be larger than estimated and vice versa. A ten percent error in assumed molt increments will lead to a ten percent error in first year losses. These losses are relatively insensitive to the assumed annual fraction molting however.

3. Migration rates

Since recent results of tagging studies are consistent with the notion that some mature lobsters may permanently migrate out of the Maine fishery, we evaluated the effect of that potential migration on projected egg production and catch. Results of the cooperative tagging study in Maine

(Daniel et al) indicate 10 to 15 percent of mature lobsters may migrate permanently out of the area in which they were originally caught. To evaluate the effect of this migration on model results we made several runs with assumed permanent migration from the inshore stock (essentially increased natural mortality) of 10 percent and 20 percent per year for lobsters greater than 100 mm. The results in Table 5 indicate that the measured ammounts of migration have little effect on our results.

Table 5. Sensitivity to offshore migration.

% migrating when longer than 100 mm	% increase in catch*	% increase in egg production*
10	6.7	88.0
20	6.4	60.0

*These are to be compared with the 6.8% increase in yield projected without migration assumed, and the 95% egg production increase, both associated with moving from the base case to 85 mm.

VI. Conclusions and Recommendations

Based on our modeling results and review of the current state of knowledge, we can now discuss the pros and cons of various proposed changes in lobster management in Maine. We summarize here the gains and losses in terms of egg production and both long and short term yield, as well as the impacts of uncertainty on projected results. To these we add other, more qualitative considerations of factors not included in the model. As can be seen here each option has both positive and negative aspects, and no single options stand out as a clearly preferred choice.

One of the proposed changes in policy is an increase in the gauge by 1/8 inches to 3 5/16 inches. Our model predicts that long term yield would increase by 5.4% and egg production would increase by 70% percent as a result of this change. Making this change as a once and for all gauge increase in one year would decrease catch in the first year by 16% followed by pre-change catch by the second year, and reaching the long term gain of +5.4% in the fourth and subsequent years. A slower adjustment could be undertaken, of course, which would reduce the first year sacrifices but lengthen the period it takes to achieve the long term yield (and egg production) increases. A first year gauge increase of 1/16 inch would reduce first year catch by about 8 percent, for example. In terms of revenues, our model suggests that total revenues will increase in the long run, roughly proportional to the yield increase. The size distribution of catch will shift so that fewer chix are caught, the same number of 1 1/8 lobsters, and more quarters, halves, and selects. In the long run, the overall gains made in the larger-sized markets more than compensates for the losses in the chix markets.

Since these projections depend on the values used for various population parameters, we also consider how they may be in error if the values used are incorrect. Long term yield projections are extremely sensitive to natural mortality rate and that parameter is poorly known. For example, if natural mortality rate is actually 0.2 rather than 0.15, the long term increase in yield would be near 3.9 percent rather than 5.4 percent. The short term decline in yield is sensitive to growth rate (specifically, fraction molting each year). However, since we have direct estimates of the loss in the first year and good estimates of growth rate, we can be reasonably confident in our first year loss estimates for once and for all changes as well as more gradual changes.

Fishermen have proposed that moving the gauge up would shorten the "size window" over which they could fish, and thereby reduce projected gains. This is predicated on the idea that lobsters over a certain age migrate out of the fishable area. Our results show that putting measured migration rates into the model changes projected gains in catch by an insignificant amount. Shortening the "size window" does not appear to be a problem for two reasons: (1) lobsters do not begin any long distance, permanent migration until about 100 mm at which size at least 90 percent of them have been caught in the fishery and (2) the fraction undergoing long distance migration is about 10 percent of those alive at the larger sizes, hence would have a negligible effect on yield.

Another contemplated management action is to remove the upper size limit. Our model predicts that this will have little effect on landings but it will decrease annual egg production to 70% of its former value. It should be stressed, however, that our model is one of the inshore population where as the more important policy issues have to do with the impact on offshore fishermen. Our yield and egg production calculations thus apply to the inshore population in isolation. A more complete analysis of the maximum gauge policy requires understanding of how inshore populations benefit from offshore egg production (if they do at all) and how offshore populations are affected (if they are) by migration of large lobsters out of the inshore stocks. Both of these areas of understanding are extremely uncertain at present and unlikely to be understood in this unforeseeable future.

There are several things which can be said about the maximum gauge of a qualitative nature. First a "cost" of having the gauge is that data is lost to Maine lobster scientists when lobsters are landed elsewhere but are not attributed to Maine stocks. That this occurs in widespread fashion is not denied by anyone. The real effect of the maximum, in fact is to impose some cost on those who transport these lobsters elsewhere rather than effectively prohibiting their being taken. Whatever the extra costs are (transporting them to New Hampshire, holding them until sufficient numbers are accumulated), they are unlikely to be sufficient to discourage the actual landing of very many oversized lobsters. Hence the existing regulation may probably not very effective, in fact, and in addition it reduces profits to Maine Lobstermen by imposing extra costs. Dealers add that even more costs are imposed on Maine lobstermen since dealers cannot "package" small

lobsters with oversize lobsters on certain orders--this reducing the value of legal lobsters somewhat (they estimate 10 cents per pound). If all of this is true, removing the maximum gauge would have little real effect (since these lobsters are being taken anyway) other than encouraging more effort as a result of the "savings" in extra costs that are now associated with extra trips, holding lobsters, etc.

A third possible policy option is dependence on V-notching. From model results, V-notching has little effect on yield and can have a substantial positive effect on egg production. One practical problem at present is that we have no firm idea of either how many V-notched lobsters are in the population or how many are being V-notched on a regular basis. The recorded numbers being V-notched by DMR amount to less than 2/10 of one percent of females landed but it is unclear how many additional lobsters are being voluntarily V-notched by fishermen. If as many as 11% of berried females trapped are V-notched and returned, the V-notching program could produce as many eggs as would result under a gauge increase to 3 5/16 inches. Thus the V-notching program holds substantial promise as a means of protecting the brood stock. It would be important, however, to couple any stepped-up program with a monitoring and sampling program in order to get some estimates of population abundance of V-notched lobsters. In addition, there has been no attention given to the possible effects of V-notching on molting, extension, and mortality, of individual lobsters. If any of those effects are significant, our estimates of the contribution of V-notching could be substantially overstated.

In searching for a "best" policy to adopt at this point, we have found, perhaps not surprisingly, that no single option clearly emerges as the best policy. We found instead, that there is an enormous range of choices possible from which to select courses of action. Each option involves different long and short term impacts and each one is predicated on various assumptions about which we have varying levels of confidence. It is important to realize, however, that we will never be able to understand all facets of this complicated system with perfect certainty. This being the case, it is important to think about what decision process is suitable for making decisions in the face of the type of uncertainty we now face.

Our overview of the current situation has brought us to the conclusion that the current policy-choice process is one which basically escalates conflict. As we pointed out at the beginning, lobstermen and managers have been arguing about virtually the same issues for nearly 90 years. Still, conditions have not remained absolutely unchanged. We have found, for example, a general willingness of industry participants to confront the uncertainties present and deal with them rationally, in short, to uncover "facts" as they exist and accept their implications. Both lobster biologists and lobstermen are better informed and better educated than their predecessors and both groups understand more about this complex system they are dealing with. In the final analysis, however, both groups are still locked in an adversarial struggle (which periodically must be arbitrated) rather than one of resolution and agreement. As we pointed out, there are sound reasons for this state of affairs that largely have to do with common property institutions.

It is our contention, therefore, that the task of altering the policy decision process towards one which fosters consensus is as important as learning more "facts" about the system. Since "facts" will never really be absolute, it is important (perhaps helped by some institutional changes) to bring lobstermen, management biologists, and outside scientists together rather than continuing in parallel and adversarial postures. In the final analysis, lobstermen and managers have the same basic interests in ensuring a viable and "safe" industry. At issue presently is whether there is a problem with stock safety and if so how to make it safer. As we discussed, there is no real way of knowing with certainly whether the fishery is in a precarious state or not. It is fairly certain that it is moving towards a less "safe" position and will continue to do so as effort intensifies. Thus there is at least a reasonable case to be made that it would be in everyone's best interest to consider policies that increase egg production.

A. Research Needs

Our study points to several critical questions that need to be answered through specific research projects of varying priority, scope, and duration. Some of these questions can be answered in a short time (i.e. one to five years), while others will require a longer period. Some are amenable to "in house" research conducted in Maine—for example, within the University system and/or DMR. Others require larger scale or specialized research effort and would be better addressed by others or through cooperative ventures (e.g. with NMFS, other states, or Canada).

Our analysis points up the need for more study of V-notching. Micro-level studies are needed to determine whether V-notching has any impact on lobster growth, survival, and reproduction. In addition, more concerted effort needs to be directed towards carefully designed and conducted population analyses which give some insight into exactly how many V-notched females are surviving and what their egg production is. This is required to determine whether or not the program has, in fact, contributed significantly to egg production. Dependence on V-notching to enhance stock safety would require an ongoing sampling program (of adult lobsters) to monitor its impact.

Perhaps equally important are needs for further study of migration and movement of lobsters. This would enable a firmer understanding of how many lobsters (if any) are being "lost" to other fisheries as well as better knowledge about whether there is a link between inshore and offshore stocks. A concerted effort to understand the linkages between these two stocks, in fact, would also help unveil some of the uncertainties surrounding stock safety inshore. Studies of larval transport and the role of Gulf of Maine currents and environmental conditions are essential to our basic understanding of recruitment processes. These studies, however, will be expensive and of long duration.

Any studies which help narrow the range of opinion about important growth and mortality processes and parameters would be helpful. There is

enough evidence on growth increments, molting schedules and molt frequency, sexual maturity and fecundity to foster some consensus among scientists over these factors. More study on Maine populations would serve to enhance confidence in these estimates and narrow the range of uncertainty involved. With respect to mortality rates, there is a greater need to narrow our uncertainty but at the same time less likelihood of being able to do so. Studies of unfished populations are required to adequately determine natural mortality and these are unlikely to be forthcoming. Some insight might be obtained by studying the component of the Maine fishery which is supposedly unfished (lobster over 5" inshore) but unfortunately this would be distorted by migration and landings made in other states. Further analysis of the size distribution data that has been collected by DMR could shed light on recruitment, growth, mortality, and migration.

B. Forging Consensus

As we have stated, it is our conclusion that breaking down existing barriers between industry participants and achieving consensus about what we know is as important to better management as further scientific study. Opening up interchange would serve to reduce the conflicts that have arisen and become real impediments to progress. Perhaps the best way to do this is to bring industry representatives together with lobster biologists and other scientists in order to "trade knowledge" about what is known of lobsters. Industry representatives need to know, for example, how scientists gather data about processes, how estimates of certain parameters are made, how much confidence can be placed on those estimates and what difference it makes to projected outcomes. Scientists on the other hand, need to know more about the collective wisdom of the individuals who work most closely with the population on a daily basis. There is often a great deal of insight to be gained by learning the "language" spoken by others over the same issues.

Once the areas of agreement and disagreement are delineated, it will be possible to move the next step, which is to sort out the implications of basic disagreements. This is most easily accomplished by using a policy modeling exercise of the sort we have developed in this study. It is impossible, after all, to judge how different beliefs over individual components of this system (e.g. migration assumptions, growth rates, V-notching impacts) affect conclusions about the system as a whole without some structured way of putting it all together. A group-effort policy model is probably the most useful means of understanding implications. For example, if some believe that older lobsters migrate out of the fishery after a certain size, it is a simple matter to try this possibility in a model and see if it makes a difference. Similarly, if lobster biologists believe that V-notching causes extra mortality or cannot be implemented beyond a certain fraction, these assumptions can also be tested to gauge their implications. In the final analysis, there are so many complexities in this system that we cannot begin to move ahead with any consensus until affected parties sit down and systematically explore options together.

One concrete way to get this started would be to put together a formal research unit whose explicit purpose would be to expand the

scientific bases for decision making and to help provide inputs to policy making. Ideally this could be funded out of both State and industry funds and staffed with personnel who are deemed credible by management biologists and lobstermen. In fact, what is needed are systems-oriented population biologists who have training and experience in policy-modeling and are working on the interface between science and the fishery. Once staffed and budgeted with a reasonable promise of continuity, the research unit could proceed on two fronts. First, it could propose and embark on a series of studies (with the aid of DMR and lobstermen) such as those outlined above. Second, it could begin the process of "mediating" existing differences between management biologists and lobstermen as also discussed above. Basically the long term goal would be one of fostering dialogue and "opening up" the process of decision making. It is possible, in fact, that future policy making could move more towards policies jointly agreeable to lobstermen and managers rather than continuing with policy disputes that must be arbitrated by the legislature.

APPENDIX 1:

LITERATURE REVIEW

Papers specified in RFP

Acheson, J.M. and R. Reidman. 1982. Biological and economic effects of increasing the minimum legal size of American lobster in Maine. Trans. American Fish. Soc. 111:1-12.

This paper is an analysis of a proposed increase in the lower size limit from 81.0 to 88.9 mm carapace length (CL) over a five year period. The purpose of the paper is to provide affected parties with a biological and economic evaluation of the overall (both long and short term) effect of this action.

The Acheson/Reidman (A/R) study is basically a dynamic yield-per-recruit computation. They attempt to compute the yield each year as the minimum size limit is changed from 3 and 3/16 inches to 3 and 1/2 inches in 1/16 inch increments. The method used, which is based on a method developed by Hancock (1975), is "driven" by data describing the current length distribution. A/R developed their own length distributions from interviews on 18 lobster boats in 6 months of 1977 and 1978. These were similar to those of Thomas in the same year except that A/R found more lobsters in the range of 81.0 to 84.0 mm CL. To generate annual yields from this model A/R used Thomas'(1973) value of 0.1 for instantaneous natural mortality (but also noted the high variability in estimates of this parameter), 13 to 15 percent annual growth rate, size at sexual maturity from Krouse (1972), and 30 percent of sexually mature lobsters berried at a time (From Thomas' data). They assume: 1) constant recruitment, 2) constant effort, 3) no change in trap vent size until the fourth year, 4) a length versus weight relationship from Thomas (1973), and 5) that their length distribution is general.

The method used to compute annual yield assumes that yield is taken from the original size distribution of catch each year plus whatever changes occur in the catchable size distribution due to lobsters not caught in the previous year. The latter are assumed to have undergone natural mortality and they either become berried or molt. One possible problem with this method is that after the first year in which "uncaught" lobsters grow into the population, they are not considered again (i.e. their contribution in the following years is not accounted for).

The A/R results are presented in terms of a case with the "most likely" parameter values and cases with "optimistic" and "pessimistic" values. In the most likely case numbers are down by 12 percent and weight is 7.9 percent above normal in the long run. These are questionable. Numbers are estimated to drop an amount greater than the annual mortality rate used, even though the size limit has been increased by an amount less than the annual growth increment. Long term yield appears to be biased low because of some problem with the method of calculation, possibly the one mentioned above.

The economic component of the A/R model links their projections of changes in lobsters caught to changes in fishermen's incomes. This is accomplished by estimating a demand curve for lobsters, essentially a relationship between the amount of lobsters that Americans have consumed and the price they have paid for them in the past. A/R use annual data (1947-78) on aggregate U.S. consumption, national income, and prices to statistically estimate a demand curve. The model used fits the data reasonably well ($R^2=0.66$) with a very significant estimated coefficient for the important lobster price variable. This coefficient is critical because it summarizes the elasticity of demand, in this case estimated to be -1.292. for the base year (1977). This implies that a 1.292 percent decrease in lobster landings will induce a one percent increase in price per pound.

The result of the biological and economic analysis is that the proposed incremental carapace length changes would generate a 13 percent "rate of return" for the most likely parameter values. That is, although revenues would initially fall, then later rise, if one views the overall process as an investment process, the yield in the long term would be about 13 percent.

The shortcomings of the economic modeling (most acknowledged by A/R) are:

i) demand curve estimates are done by regressing total U.S. consumption on Maine ex-vessel prices. A conceptually sounder method would be to estimate consumption demand as a function of wholesale (or retail) prices and then determine how ex-vessel prices in Maine are related to wholesale or retail prices.

ii) The data used to estimate demand are annual data. A more accurate model would account for the intra-seasonal price variations, particularly if it is believed that relative monthly supplies might change with proposed carapace length changes.

iii) A/R ignore the effects of lobster size on market price determination. If the market is segregated in the sense that different groups with different characteristics demand lobsters of different sizes, there could be important and complicated substitution relationships missing in an analysis which aggregates lobsters into total pounds or total numbers.

iv) The authors assume that effort will not change as carapace length policies are introduced. This simplifying assumption allows them to ignore the cost side of the problem and focus only on the revenue side. If effort does respond, the net effects on the industry will not be adequately measured by examining revenues only.

Finally, it should be noted that the results of the demand curve or elasticity estimates apparently do matter substantially in the overall analysis. A/R report results of a sensitivity analysis around their reported elasticity estimate which uses more and less elastic demand curve assumptions. Using most likely biological parameters results in rate of

return estimates of 0 percent, 13 percent, and 43 percent for the "most elastic", "likely", and "least elastic " demand curve estimates, respectively. Thus, even if we can be absolutely confident of our biological parameters, the span of corresponding elasticity parameters which falls within the range of statistical possibility leaves us in a "grey area" of uncertainty regarding potential returns to fishermen.

Anonymous. 1980. Scientific recommendations for management. In Proceedings Canada-U.S. Workshop on status of Assessment Science for N.W. Atlantic Lobster (Homarus americanus Stocks (St. Andrews, N.B., Oct.24-26, 1978) (ed. Anthony,V. and J. F. Caddy). Can. Tech. Rep. Fish. Aquat. Sci. 932:180.

This is merely a one page summary of the recommendations that resulted from the 1978 workshop, and hence doesn't merit a full technical review. (Several of the papers from this workshop are reviewed below.) There are, however, several important points made. There was unanimous agreement among those present that a significant increase in size limit was needed, both to increase the yield per recruit and to provide for greater reproduction. A decrease in effort levels was also recommended. Participants expressed concern over escape vents and ghost fishing. Cost-benefit analyses of any proposed management changes were recommended. The roles of research surveys and statistical reporting systems were emphasized. An issue of particular importance here, that stock boundaries do not coincide with geographical boundaries (i.e. state or national boundaries), was also noted.

Bennet, D.B. and E. Edwards. 1981. Should we ban the berried lobster? ICES CM 1981/K:11.

This paper is a review of recent evaluation of the regulations regarding landing of berried lobster in the Homarus gammarus fishery in the U. K.. A regulation prohibiting the landing of berried lobsters was repealed in 1966 because it: (1) was too difficult to enforce and (2) could not be shown to definitely increase recruitment. Since stocks have been declining in recent years, presumably because of declining recruitment, managers are considering changes in regulations. Both the long term and the short term benefits of four different options were considered in this paper. The options were: (1) increasing the size limit from 80 mm to 83 mm, (2) increasing the size limit to 85 mm, (3) increasing the size limit to 85 mm for females only, and (4) banning the landing of berried lobsters. All of these were predicted to lead to short term losses in the first year, that varied with biological parameters of the stocks. Long term gains in yield-per-recruit were incurred by all of the increases in lower size limit while the ban on berried lobsters showed slight losses in the long term. All yielded an increase in egg production, with the greatest gains achieved by the ban on berried lobsters.

After considering these results and ease of enforcement, British managers decided to increase the size limit in two steps, first to 83 mm,

then to 85 mm. They did note, however, that in the face of declining recruitment it would not make sense to repeal a ban on landing berried females if one already existed.

Campbell, A. 1985. Application of a yield and egg-per-recruit model to the lobster fishery in the Bay of Fundy. N. Amer. J. Fish. Mgt. 5:91-104.

This paper begins with a statement of the perceived problem. Although stocks have remained at a constant level in recent years, the increasing fishery for large animals and the increasing offshore fishery have caused concern that the fishery should be better protected against recruitment failure. Campbell then reviews the various management regulations used in Canada. The purpose of the paper is to evaluate some of the management options, not just in terms of yield per recruit, but also in terms of eggs per recruit. The options evaluated are: (1) minimum size limit, (2) maximum size limit, and (3) closed size window.

The evaluation of the various options is basically a static yield (and egg)-per-recruit analysis. The model used is one developed by Caddy (1977, 1979) and differs from most others in that it is indexed according to molt number rather than time. This leads to difficulties in the way in which time is expressed in the mortality expressions. The time period over which mortality affects individuals is taken to be the inverse of annual molting probability. Mortality would be more accurately represented as mortality at a constant rate over the actual intermolt periods (i.e. a certain fraction having an intermolt period of only one year, and a smaller fraction an intermolt period of two years, and so on). The effect of this assumption on overall model behavior is probably not great. A second potential problem is the representation of the proportion extruding eggs as "half of the intermolt period up to a maximum of about 1.7 ...". The proportion molting could not be greater than 1.0.

The growth model is expressed in terms of molt increments and the fraction molting each year based on tagging studies by Campbell (1983). Maturity and fecundity at each size is based on data from Campbell and Robinson (1983). Current instantaneous fishing mortality rate is estimated to be 1.4. Natural mortality is taken to be 0.1 from Thomas (1973), but values of 0.05, 0.20, and 0.30 are also used.

The yield-per-recruit results were expressed in terms of a plot of catch versus fishing mortality for various options. It showed that at current fishing mortality rates there is little to be gained from a change in fishing mortality as compared to a change in size limit. Policies that involved closed windows also had little effect on yield. The only effect of the maximum size limit was to remove the peak in yield at lower fishing mortality rates. Another important point made regards the effect of the natural mortality assumption. The benefit of an increase in size limit is much less if the natural mortality rate is higher. For example, the benefit of increasing the size limit to 90 mm is a 21.3 percent increase in yield with the assumed natural mortality rate of 0.1. For a natural mortality rate of 0.3, it is only 5.6 percent.

The effect of the various options on eggs per recruit was positive for all of them. A point of interest to the state of Maine is that with an upper size limit in place, the percentage increase in egg production due to an increase in lower size limit is the same as if it were not in place, but the starting point is higher.

Campbell concludes that an increase in lower size limit is the best option. The recommended amount is one molt increment, but this is probably due to the molt-oriented structure of the model used. He notes that the effects of increased eggs per recruit will be difficult to assess because the stock recruitment relationship is so poorly understood. He includes a brief discussion of that problem.

This study is valuable in that it points out some of the salient features of the yield per recruit calculation. It does not, however, provide a complete answer to our problem because: (1) it is a static analysis (i.e. it does not describe the dynamic transition from one management regime to another) and (2) it does not consider the changes in effort, price, demand, etc. that result from a change in regulations.

Campbell, A. and D.G. Robinson. 1983 Reproductive potential of three American lobster (Homarus americanus) stocks in the Canadian Maritimes. Can. J. Fish. Aquat. Sci. 40:1958-1967.

This paper reports the results of examination of lobsters at different sizes from 3 locations (Bay of Fundy, Northumberland Strait, and eastern Nova Scotia) to determine sexual maturity. To determine maturity Campbell and Robinson (C/R) examined the pleopods for well-developed cement glands. They also measured the number of eggs and computed the relative contribution to egg production at each size.

The results of the data collection are presented in terms of an equation describing the increase in proportion mature as carapace length increases and an equation describing the increase in fecundity with carapace length. The relative contribution of each size to total egg production was computed assuming one extrusion per intermolt period. (The effects of multiple extrusion were negligible at high values of fishing mortality.) The cumulative relative contribution increased rapidly with carapace length. A point of interest here is that for the Bay of Fundy this increased contribution does not begin until carapace length is considerably greater than the current minimum size limit.

C/R note that although egg production per recruit under current regulations is lowest in the Bay of Fundy region, the fishery there has remained constant while it has declined in the other two areas. He speculates that this is due to the existence of an offshore refugium in which reproductive lobsters are relatively protected (i.e. lightly fished, at least in the past). He recommends an increase in size limit.

Campbell, A., D.E. Graham, H.J. MacNichol, and A.M. Williamson. 1984. Movements of tagged lobsters released on the continental shelf from Georges Bank to Baccaro Bank, 1971-1973. Can Tech. Rep. Fish. Aquat. Sci. 1288:16p.

This paper reports the results of analysis of returns from tagging and releasing lobsters in 1971 through 1973 from Welker Canyon on Georges Bank north to Baccaro Bank. Two types of tags were used, one of which was easily lost during molting. Returns were grouped by: (1) distance travelled, (2) depth of capture, and (3) time at large. To compare the results with earlier results indicating seasonal onshore-offshore migrations, these were grouped into quarterly periods.

The analysis indicated 71.8 percent were captured within the first year, and this declined gradually to 1.3 percent being at large for 8 or 9 years. Forty two percent of the recaptures had moved less than 18.5 km (9 nautical miles) and only 12.7 percent had moved greater than 92.6 km (50 nautical miles). This result differed from other studies of inshore populations (i.e. Campbell 1982) in which tagged lobsters (mostly immature) moved shorter distances. The long distances support the notion that lobsters inshore and on the continental shelf are a common stock. The results were also consistent with earlier indications that lobsters migrate seasonally from shallow waters in the summer to deeper waters in the winter.

Campbell, A. and A.B. Stasko. 1985. Movements of tagged American lobsters, Homarus americanus, off southwestern Nova Scotia. Can. J. Fish. Aquat. Sci. 42:229-238.

This paper reports the results of analysis of returns from lobsters tagged and released off southwestern Nova Scotia and Browns Bank during 1975. Of the lobsters released inshore 7.5 percent were recaptured, and of the lobsters released offshore 15.3 percent were recaptured. In both areas combined, mature lobsters (greater than 95 mm CL) moved a greater distance (15.6 km) than immature lobsters (4.7 km). Most of the recaptures from immature releases (69.3 percent) had moved less than 18.5 km while most of the recaptures from mature releases (59.5 percent) had moved more than 18.5 km. Offshore immatures moved farther than inshore immatures, but there was no difference between matures. Depth of recapture was greater for mature lobsters. There was no clear direction of preferred movement.

The importance of this study is that it shows long distance movement of inshore lobsters and greater movement of mature than immature lobsters. One point that could be questioned is whether mature lobsters retained tags longer because they molt less often. This would allow them to show greater distance traveled, merely because of longer time to travel. Another major point of importance is that this study again suggests that the inshore and offshore stocks are not isolated.

Ennis, G.P. Canadian efforts to assess yield per recruit in lobsters. in Proceedings Can.-U.S. Workshop on Status of Assessment Science for N.W.

Atlantic Lobster (Homarus americanus) Stocks (St. Andrews, N. B. , Oct. 24-26, 1978) (ed. V. Anthony and J.F. Caddy). Can. Tech. Rep. Fish. Aquat. Sci. 932:45-49.

In this brief paper Ennis points out that there are two Canadian models for assessment of yield per recruit, one developed by Caddy (1977) and the other by Ennis and Akenhead (1978). Both model growth by molting explicitly. He notes that generally yield per recruit analyses for Canadian stocks have shown that yield is more sensitive to changes in minimum size limit than fishing pressure.

Ennis, G.P. 1985. An assessment of the impact of size limit and exploitation rate changes on egg production in a Newfoundland lobster population. N. Amer. J. Fish Mgt. 5:86-90.

Ennis uses a model similar to Caddy's (1977,1979) model to analyze yield per recruit. The model apparently differs from Caddy's in that it is indexed by time rather than molt. This would avoid some of the problems associated with expressing the time over which mortality is in effect (see above review of Campbell 1985).

Ennis' results show that moving the lower size limit from 81 to 89 mm results in a 144 percent increase in yield, changing the fishing mortality rate from 0.8 to 0.6 results in a 90 percent increase in yield, and enacting both results in an increase of 270 percent. For the Newfoundland population he has modeled, 49 percent of the egg production is currently by sublegal lobsters because of their low age of maturity. He discusses the poorly known relationship between egg production and recruitment in this species.

Harding, G.C., K.F. Drinkwater, and W.P. Vass. 1983. Factors influencing the size of American lobster (Homarus americanus) stocks along the Atlantic coast of Nova Scotia, Gulf of St. Lawrence, and Gulf of Maine: a new synthesis. Can. J. Fish. Aquat. Sci. 40:168-184.

The authors compare various lobster stocks in order to determine the factors that control abundance. They are mainly concerned with decline of stocks in the Gulf of St. Lawrence. Although this is of some interest here, this review will concentrate on material relevant to the Gulf of Maine.

Harding et al. first evaluate the hypothesis that construction of the Canso Causeway was responsible for the decline of stocks in Chedabucto Bay by computing the number of larvae that would have been transported if the causeway were not there.

They then evaluate several different hypothetical causes of fluctuations (mainly declines) in lobster stocks. With regard to fishing pressure, they conclude that excessive fishing pressure may be responsible for the decline in some lobster stocks, but that this is difficult to prove because of inadequate measures of effort. With regard to environmental influences, they note that post World War II Maine lobster landings are

correlated with coastal sea surface temperatures 5 to 8 years earlier (Dow 1972; Flowers and Sails 1972), but that correlations between landings and temperature are not significant in eastern Nova Scotia or the Gulf of St. Lawrence.

They next discuss the sea urchin/kelp hypothesis (Mann and Breen 1972; Wharton and Mann 1981). Briefly, this hypothesis is that lobster populations normally control sea urchin populations through predation, but when they are fished down to low levels, sea urchin populations increase unchecked and devastate kelp beds so that productivity is low and large lobster populations can no longer be supported. This may explain the lobster declines in eastern Nova Scotia, but the theory involves many uncertainties. These may be resolved by the current epidemic in the urchin population.

Their discussion of the next factor, larval recruitment, centers around the Huntsman (1923) hypothesis that lobster larvae settle successfully only if they have a sufficient number of days of high enough temperatures. They also discuss variation in larval food resources.

They propose that stocks bordering the Gulf of Maine are a single stock with common recruitment. This recruitment comes from the warm, productive Georges Bank area and is affected by temperature fluctuations in that region. They then propose hypothetical explanations for the east coast of Nova Scotia and the Gulf of St. Lawrence.

The value of this paper for our purposes is that it outlines hypotheses regarding how some lobster populations, in particular those in the Gulf of Maine, might work.

International Workshop on Lobster Recruitment, St. Andrews, New Brunswick, Canada, June 30 -July 5, 1985.

Several papers given at this workshop were pertinent our purpose here. These brief reviews are based on one or more of: (1) a copy of the paper, (2) the abstract, or (3) Botsford's notes taken at the meeting.

1. Bannister, R.C.A. and J.T. Addison. Stock recruitment relationships and the long term dynamics of the European lobster (Homarus gammarus L.)

The authors analyze the effect of changing size limits and fishing mortality on overall yield when a stock-recruitment relationship is included. The important point here is that when the population has a stock-recruitment relationship with a negative slope, increasing egg production can cause a decline in recruitment.

2. Campbell, A. and D.S. Pezzack. Overview of movement patterns, relative distribution and abundance of lobsters, Homarus americanus in the Bay of Fundy and off southwestern Nova Scotia.

The authors discuss the use of multiple mark-recapture information to define inshore/offshore migration. They present a model that demonstrates how temperature is optimized by migration. They also relate the geographic location of ovigerous females, about to release eggs, to oceanographic conditions.

3. Daniel, P. R. Bayer and J. Krouse. Movements of large tagged female American lobsters, released near the Maine coast in the fall of 1983.

This abstract reports results thus far of analysis of returns from the joint tag and release program by University of Maine, Orono and the Maine Lobstermen's Association. The full paper was obtained and is reviewed below.

4. Ennis, G.P. Stock definition, recruitment variability, and larval recruitment processes in the American lobster, Homarus americanus.

This paper is a general review of recruitment processes in Canadian waters.

5. Fogarty, M. J. Implications of alternative stock-recruitment relationships for the stability of lobster populations.

The author showed that the available data indicate that the lobster stock-recruitment relationship is probably of the asymptotic type.

6. Harding, G., J. Pringle, and P. Vass. Vertical migration of lobster larvae.

The authors reported finding that first and second stage larvae undergo diurnal vertical migration, whereas the last two stages do not appear to migrate synchronously. These findings indicate that it will be difficult to show that larvae which hatch offshore are transported to inshore settlement areas.

7. Hudon, C. and P. Fradette. Horizontal and vertical distribution of lobster larvae (Homarus americanus) off the Magdalen Islands, Gulf of St. Lawrence.

The authors find that only stage I larvae migrate vertically (compare to paper 6). This paper is mentioned here to demonstrate the primitive state of knowledge of lobster larval behavior and transport.

8. Pezzack, D.S. and D.R. Dugan. Lobster (Homarus americanus) migrations on the southwest Scotian shelf.

The authors report results of a multiple recapture tagging study. Results showed seasonal migration and return migrations greater than 150 km in length.

9. Meyer, T., J. Uzmann, R. Cooper, and M. Fogarty. Preliminary report on a lobster tagging study in the central Gulf of Maine.

The authors report preliminary results of a multiple recapture tagging study. The results show extensive movement from the shelf to the U.S. and Canadian coasts. This study is pertinent to our purposes here and should be closely monitored.

10. Waddy, S.L. and D.E. Aiken. Multiple fertilization and consecutive-year spawning: Mechanisms for increasing the reproductive contribution of large female American lobster.

The authors note that because of recently observed spawning in consecutive years (instead of every other year) and multiple spawnings within a molt period (rather than a single spawning), older lobsters may provide a much larger contribution to egg production than was previously thought. This is important to our purposes here, but we must still consider the fact that because of high fishing mortality, very few females reach the age at which this occurs.

Fogarty, M.J. 1980. Assessment of yield per recruit for the American lobster (Homarus americanus). In Proceedings Can.-U.S. Workshop on Status of Assessment Science for N.W. Atlantic Lobster (Homarus americanus) Stocks (St. Andrews, N.B., Oct. 24-26, 1978) (V. Anthony, J.F.Caddy, eds.). Can. Tech. Rep. Fish. Aquat. Sci. 932:37-44.

This paper is a summary of the static yield per recruit analyses for lobster in U.S. waters performed by the State-Federal Lobster Scientific Committee. Growth is described as a continuous function rather than describing molting explicitly. Derivation of growth curves is not given in this paper, but molts were assumed to occur annually. Growth and mortality were derived from tagging data and length frequency analysis of catch data, and they vary by area. The natural mortality rate used is 0.15, although sensitivity of results to the value of this parameter is evaluated by computing changes using values of 0.10, 0.20, and 0.30.

Results are presented in terms of the optimal fishing mortality rate for a given lower size limit, and the optimal lower size limit for a given fishing mortality rate. Current values of the former are generally an order of magnitude too high, and current values of the latter are too low. The latter was quite sensitive to the value used for natural mortality rate. On the basis of the results obtained an increase in the lower size limit to 89 mm is recommended. Fogarty also recommends attempting to develop an effort limitation scheme.

Fogarty, M.J. 1983. Distribution and relative abundance of American lobster, Homarus americanus, larvae; a review. SSRF 775:3-8. NOAA Tech. Rep., NMFS, Washington, D.C.

This report is a summary of the various surveys of lobster larval distribution and abundance that were conducted in New England during 1974 through 1979. It begins with a review by Fogarty of the characteristics of

American lobster larvae. Larvae are found near the surface during daylight hours, but may be below the surface at night. Investigations of phototactic response have produced mixed results. Larvae have been shown to have both positive and negative responses and these vary with stage and time within stage. (Note: These mixed results may result from larvae being attracted only to an intermediate light levels, and their performance being sensitive to other experimental conditions.) Larvae have been shown to grow faster at higher temperatures. They are also believed to be transported by surface winds. The relationship between stage IV larval abundance and subsequent stock size appears to be an asymptotic stock recruitment relationship. On the basis of the reviewed studies, Fogarty concludes that the prevailing southwesterly winds off the New England coast may transport larvae shoreward.

The next article is a summary of the various larval sampling projects in New England during 1974-79. This is followed by articles describing the individual sampling programs at various locations. In these studies larvae were typically shown to be sensitive to light and temperature and to be influenced by wind. However, because of the variability of results and the fact that the question of importance here (i.e. what is the source of recruitment for the inshore lobster fishery in Maine?) is far from being answered, the remainder of the report is not reviewed in detail here.

Fogarty, M.J., R.A. Cooper, J.R. Uzmann, and T.S. Burns. 1982. Assessment of the USA offshore American lobster (Homarus americanus) fishery. ICES, C.M. 1982/K:14, 21p.

This evaluation of the offshore fishery begins with a brief review of the research done over the past several decades on the offshore populations. The history of the fishery is then reviewed. This fishery was solely a trawl fishery in the 1950s and early 1960s. The trap fishery developed rapidly, however, in the late 1960s and early 1970s. Landings increased from 50 MT in 1969 to 2900 MT in 1973, and then were constant until a recent slight decline. An index of abundance (catch-per-trap-haul-set-over-days) declined from 1969 to 1972 and has remained approximately constant since then. A biomass index from trawl surveys declined from 1964 to 1976 then increased through 1979. Both tagging data and length frequency distributions indicate an increase in total mortality rate in the late 1960s and early 1970s.

Growth and mortality rates were determined from tagging and other data, and these were used to project changes in yield that could be expected from changes in fishing regulations. Growth by molting was modeled explicitly, and several values of natural mortality were used. Results of static yield-per-recruit analyses showed that yield was more sensitive to changes in size limit than to changes in fishing effort. There was some evaluation of short term (first year) losses using the method of Hancock (1975).

On the basis of these analyses, the authors recommend an increase in lower size limit for these stocks, both to increase yield-per-recruit and to stabilize recruitment.

Krouse, J.S. 1973. Maturity, sex ratio, and size composition of the natural population of American lobster, Homarus americanus, along the Maine coast. Fish. Bull. U.S. 71:165-173.

This paper presents biological data that resulted from sampling off Boothbay Harbor in 1968, 1969, and 1970. Since they are gathered in Maine waters they are particularly pertinent to our purposes here.

Sex ratios of the samples, which included primarily sublegal lobsters were not consistently different from 1:1 over the 3 years. Data on the percentage of soft shelled lobsters for each month reflect the intra-annual pattern of molting. The computed length-weight relationship provides a good source of this relationship for the size range of 50 to 90 mm CL in Maine waters. The size distribution of sublegal lobsters was approximately uniform over the range from 70 to 80 mm CL. Based on ovarian development, 100 percent of the female lobsters were mature at 100 mm, while approximately 60 percent were mature at about 92 mm CL. A size distribution of berried females along the Maine coast showed few lobsters berried at 85 mm CL, a peak at 92 mm CL, few berried at 96 mm CL, another peak at 105 mm, then a decline to few berried females at 125 mm CL.

Morrissey, T. 1980. Change in minimum size limits, gear regulations and the berried lobster laws in the U.S. in Proceedings Can.-U.S. Workshop on Status of Assessment Science for N.W. Atlantic Lobster (Homarus americanus) Stocks (St. Andrews, N.B., Oct 24-26, 1978) (V. Anthony and J.F. Caddy, eds.). Can Tech. Rep. Fish. Aquat. Sci. 932:175-179.

This paper is a brief review of lobster fishery regulations in the U.S. All states prohibit the taking of berried lobsters, and this regulation has long been favored by fishermen. There is little gear limitation. Only one state limits the number of traps that can be fished by a commercial fisherman. Under the plan adopted by the Northeast Marine Fisheries Board all states were to have trap vents by 1981. Minimum size limits have varied over the years. Morrissey gives the history of Maine's size limit regulation as an example. Since increases in the lower size limit took place in 1942 and 1958, any available data over those years could be extremely valuable to this project. Under the plan adopted by the Northeast Marine Fisheries Board all states were to have a minimum size limit of 3 and 3/16 inches by 1981 and were to consider each year whether to move this limit up uniformly by 1/16 inch per year.

There are several interesting points in the discussion following this paper. Apparently Rhode Island increased its lower size limit recently in 1/32 inch increments. Also, there was an increase in the size limit in the Magdalen Islands in 1954 which is looked upon quite favorably by the fishermen.

New England Fishery Management Council. 1983. Final Environmental Impact

Statement and Regulatory Impact Review for the American lobster fishery management plan.

The impact statement and regulatory review of the lobster fishery management plan analyzes proposed carapace length changes for all New England lobster states including Maine. The economic component of the FMC study uses the demand work reported by Wang and Kellogg (WC) in which the percentage of lobsters under 1.25 lbs is included as a price determinant. Analysis is made of "short-term" and "long-term" impacts, the former calculated as first year losses in lobster availability using the Hancock method. The FMC study assumes: i) constant recruitment, and ii) constant fishing mortality. In addition, an extra calculation was made for the Maine fishery in order to account for the oft-stated belief that Maine lobstermen may not employ knife-edge selectivity but rather "eyeball" lobsters before they employ a gauge. Practically speaking, this would mean that fewer lobsters would appear in length-frequency catch data just above the current minimum size than would be the case were perfect knife-edge selectivity practiced. The FMC study (apparently) assumes that a fixed proportion of lobsters landed in the critical length class just above the minimum is thrown back. This assumption does matter—first year estimated losses in landings following an increase from 3 3/16 to 3 1/4 inches are 4.9% assuming knife-edge selectivity but 16.1% assuming continuation of the alleged "eyeballing" procedure. One would expect that fishermen faced with a more stringent length measure would exert more effort towards gauging more marginal lobsters (and also to learn how to "eyeball" the larger size) so that the lower figure might be closer to the post-regulation change circumstances.

The FMC may not be giving sufficient emphasis to the fact, however, that the relatively low estimated short term loss (compared to other studies) is the result of both biological events and an implicit shift in behavior by fishermen which reduces apparent impact by increasing the percentage of just-over-legal lobsters taken during transition.

With respect to the FMC translation of yield impacts into revenue impacts, the study uses demand curve estimations which account for sizes in a rough way, namely by "shifting" the curve as the percentage of small (1.25 lbs) lobsters change. The bottom line, however, is that ex-vessel and wholesale revenues change roughly by the same proportion as the landings changes. For example, with the projected gauge increase to 3 1/4" (and knife-edge selectivity), the landings in Maine are expected to fall in the short run by 4.9% (coastwide by 5.6%) and ex-vessel prices are expected to rise by 1.5%, yielding a loss in Maine revenues to fishermen of 3.5%. The implied elasticity of demand is about -3.0 (i.e. elastic).

Pringle, J.D., D.G. Robinson, G. P. Ennis, and P. Dub  . 1983. An overview of the management of the lobster fishery in Atlantic Canada. Can. MS Rep. Fish. and Aquat. Sci. 1701:103p.

This document is an overview of lobster management in the Canadian Maritimes. It begins with a statement of the problems associated with the

fishery: (1) that the fishery has been known to be overfished since 1980, yet regulations have not been changed, and (2) a size and season-dependent mismatch of supply and demand.

The Gulf of St. Lawrence stocks are influenced by varying sea water temperatures. Magdalen Islands' stocks are thought to be cyclic and stocks in Northumberland Strait have collapsed (see review of paper by Harding et al., 1983, above). Stocks off southeast Nova Scotia have declined to 5 percent of their former levels. Egg production per recruit in the 1940s was about 5000, but is now between 10,000 and 15,000. Stocks off southwest Nova Scotia and in the Gulf of Maine consist of offshore and inshore components, whose interrelationships are not understood. There has been a slight decline in the past decade. Catches off Newfoundland increased in the 1970s because of increased fishing pressure and expanded fishing areas. Because these stocks mature at smaller sizes, substantial reproduction takes place at sublegal sizes. However, this did not prevent a long term decline from 1955 to 1972.

There is some discussion of the variation in demand with size in the Canadian (international) market and the problem of matching supply to seasonal demand.

A list of recommendations is presented. Included is a recommendation to increase size limits.

Thomas, J.C. 1973. An analysis of the commercial lobster (Homarus americanus) fishery along the coast of Maine, August 1966 through December 1970. NOAA Tech. Rep. NMFS SSRF-667:57p.

Thomas first briefly describes the history of the Maine lobster fishery in term of catch, number of traps, and regulations from 1930 through 1970. He then documents currently used traps with measurements and photographs.

He then describes a couple of small biological studies. In one he collects females about to molt and measures both premolt and postmolt carapace lengths. He determines that these lobsters grow about 8 percent per molt, and notes that his value is lower than Wilder's (1953) value of 14 percent. The value of 8 percent is lower than all other measurements encountered, hence is probably an artifact of the holding conditions. The next study is measurement of the length of females that become berried in pounds. From these he determines that lobsters extrude their eggs in May or July. He comments that the fishery would be better off if the upper limit were removed and the lower one increased, because very few females make it to the upper size limit.

Thomas then describes the DMR sampling plan which involves interviewing lobstermen as they deliver their catches. Information is obtained on catch and several measures of effort, and 10 lobsters from each boat are examined and measured.

In the next section he plots the number of lobsters at each measured

length in length frequency distributions with increments of 14 percent. This increment is chosen under the belief that the length classes would represent age classes. This would be true only if (1) all lobsters molted each year and (2) each lobster's molt increment was exactly 14 percent each year. Other studies indicate that these are approximately true near 81mm carapace length. He then attempts to determine growth rate from age classes determined by picking out peaks in the length distributions. This procedure is extremely subjective, especially when growth rate is low and variable. One can have little confidence in the results of using this method.

In the next section Thomas plots two measures of catch-per-unit-effort, catch-per-trap-haul (CPTH) and catch-per-trap-haul-set-over-days (CPTH/SOD), versus temperature. Although the plots are somewhat similar in each year, the comparison leads to ambiguous results. Catch-per-unit-effort is changing within the year, but one cannot determine whether that is due to a change in abundance or a change in catchability. Thus we learn nothing by comparing these putative indices of abundance to temperature.

Thomas then plots CPTH versus SOD within each year. He claims that these show an increasing trend. One may (1970), but the others only appear to because he forces the line to go through the origin (0,0). One would expect a plot of CPTH versus SOD to increase to a constant level if the variables were independently controlled. This would indicate a trap saturation phenomenon. However, in this case fishermen are probably pulling their traps to avoid trap saturation (considering also the cost of pulling the traps), hence these plots show only a low (compared to the saturated level), variable level of catch per trap.

The next step in this document is an attempt to derive population parameters from the data. This section is particularly important for our purposes, since the parameters derived here are those used in the yield per recruit computations. He first attempts to fit a commonly used growth equation, the von Bertalanffy equation, to the size modes in the length distributions. The values obtained are questionable since they correspond to an annual increase in length of 9 percent at 90 mm CL, while the modes in the size distribution show an increase of 6.6 percent. The fact that the purported annual molt increment is 14 percent raises further question regarding this result. He also determines a weight-length relationship for sublegal and legal lobsters combined.

The next task undertaken by Thomas is an attempt to estimate mortality rates. For our purposes here, since changes in yield are relatively insensitive to variation in fishing mortality rate but quite sensitive to the value of natural mortality rate, the latter is the mortality rate of greatest interest. Thomas uses several different methods to estimate total mortality rate. These methods are difficult to evaluate for various reasons (e.g. data variables are not defined), but since most of the results are 90 percent or greater annual mortality (which is probably correct) and the total mortality is not of primary interest, we will concentrate on estimates of natural mortality here.

The first estimate of natural mortality rate involves using a method

attributed to Beverton and Holt (1957) to estimate natural mortality of prerecruit sizes. He does not describe what he has done in sufficient detail to critically evaluate it, but the results for the two years computed were 29.3 percent per year and 19.2 percent per year. The second method is a regression of total mortality on fishing effort, which yields an estimate of 7.7 percent. Since the regression involves only 3 points, this estimate is not conclusive. The next estimate uses a method attributed to Silliman (1943). Again, insufficient details are supplied to determine exactly how the estimate was computed, but the result was 22.9 percent. He then refers to several estimates made by others: Dow et al. (1953), 7 to 8 percent and Dow (1964), 28 to 33 percent.

The next step was to estimate the catchability coefficient, q . This is the constant of proportionality between fishing effort and fishing mortality. Two different methods, each involving a regression of 3 points were used. They both yielded exactly the same result (to the 3 significant figures given) for catchability coefficient, but different estimates of natural mortality rate, 7.7 percent and 43.9 percent. Other attempts yielded estimates of natural mortality that were negative. On the basis of all the computed estimates, Thomas concludes that it is near 0.10.

Thomas next uses the estimated population parameters to compute yield per recruit for various values of minimum size and fishing mortality rate. On the basis of these he recommends raising the minimum size limit to 89 mm.

The values of natural mortality rate (0.10) and growth rate (his von Bertalanffy fit) estimated by Thomas are widely used (e.g. Campbell 1985 uses the former and the federal management plan uses both). However, as outlined here there are substantial reasons to doubt the methods used to obtain them. Their questionable nature is an important issue in light of the critical dependence of yield-per-recruit results on them.

Thomas, J. C., C.C. Burke, G. A. Robinson, and D.B. Parkhurst, Jr. 1983. Catch and effort information on the Maine commercial lobster (Homarus americanus) fishery, 1967 through 1981. Maine Dept. of Marine Resources Lobster Informational Leaflet #12:182p.

This document is a compendium of the data collected from 1966 through 1981 in the lobster fishery sampling program of the Maine DMR. Each set of tables is preceded by a brief explanation of the computations made.

The first set of tables is the length distributions by month from August 1966 through 1981. Beginning in 1970, the first three months of each calendar year is not sampled.

The second set is a monthly listing of average length, average weight, fraction that are females, fraction that are shredders, and fraction that are culls. The fraction of females could be of value in assessing the effect of the berried law and v-notching. The fraction of shredders will be of value in specifying the time of molting in any yield model that includes intra-annual effects. It would be valuable to know what the codes in the

tables mean.

The next set of tables is a monthly list of various catch and effort data. These data will be valuable in estimating the dynamic response of fishing effort to changes in abundance.

The fourth set is a list of monthly average set time and hauls per month. As would be expected from the increase in catch in midyear and the decline during the last half of the year, the former measure decreases, then increases through the year, while the latter increases, then decreases.

The fifth table is the average number of traps fished per boat. The complete distribution of number of boats with a specified number of traps is shown in a figure (Fig. 4).

The next set is monthly catch per THSOD, both in terms of numbers and in terms of pounds. These generally increase until July then decline.

The seventh table contains the results of a regression of the logarithm of catch per trap haul on set duration for each month. The high values of correlation coefficient indicate set time does influence catch per trap haul.

The next table is a listing of relative fishing power. (Note: Rather than being the T^* that Thomas claims is listed, the quantity listed is apparently T^*/T .) This is not a common calculation, and is taken from a publication by Austin (1977). Thomas concludes that the fact that fishing power is greatest at an SOD of 1 explains the management paradox that when the number of traps is reduced the exploitation rate remains the same. The fewer traps are hauled more frequently. This does not appear to be a sound conclusion. Fishing power is probably greatest at an SOD of 1 because when abundance is greatest, traps are hauled every day to prevent saturation.

In the next table he presents the results of computing the ratio between fishing effort and fishing mortality rate, the catchability coefficient, q .

The next table is a monthly listing of $1/q$. He uses this together with average hauls per month and mean SOD for each month to compute the number of traps that would correspond to $F=1.0$. This method of determining the limit to the number of traps that would be necessary to reduce the fishing mortality rate to 1.0 is no better than reducing the number of traps fished each month by the proportion indicated by the estimated fishing mortality rate for that month. Both of these are of dubitative value, however, because neither accounts for the change in fishermen's fishing behavior in response to a trap limitation.

The next table is a listing of estimates of total mortality. Since he does not specify the quantities used in the calculations, it is difficult to evaluate these.

The next three tables contain results of estimating mortality rates

using a method based on the annual size distribution, effects of a reduction in effort on yield that are somehow based on the same method, and an evaluation of the short term effect on yield of changes in effort. It is difficult to determine, from the information given, the relative reliability of these results.

The next table uses the various CPUE measures computed from the sampling, and the total Maine catch to estimate total effort of the various types (man-days, traps, etc.). In a similar fashion the next table presents expansion of the size distributions to total numbers using the total Maine catch. The next table is total monthly Maine landings by county.

The next table is an attempt to determine a stock-recruitment relationship from an estimate of egg production and recruitment. Since he doesn't specify how either is computed, this is difficult to evaluate.

The last table presents the results of computing regressions of monthly effort (in boat-days) on monthly seawater temperature, fog, wind speed, and number of days with wind greater than 20 mph. Since he doesn't mention having removed the annual cycle from these variables, the high regression coefficient coefficients obtained probably result from seasonal covariation, rather than the response of fishing effort to these environmental variables.

References Added to List in RFP

Krouse, J.S., R. Bayer, P. Daniel, E. Blackmore, and J. Vachon. Maine lobster migration study.

Krouse, J.S. Progress report of the DMR,MLA, and UMO cooperative lobster tagging study.

Anon. DMR, MLA, UMO cooperative lobster tagging study-second year-1984

Cerullo, M. Lobsters--and research study--making progress.

These four documents report the results thus far of the cooperative tagging study. Approximately 1000 lobsters were released in both Stonington and Booth Bay Harbor in the falls of 1983 and 1984 (about 4000 total). This work is referred to above in the Lobster Recruitment Workshop (Daniel et al.) and the complete preliminary manuscript is reviewed below

Daniel, P.C., R.C. Bayer, and S. Vaitones. Preliminary estimate of contribution of v-notched American lobsters (Homarus americanus) to egg production along coastal Maine based on Maine Lobstermen's Association V-Notch Survey. 24p.

Bayer, R. C. Letter to Senator Jean Chalmers dated April 23, 1985.

Bayer, R.C. Estimated egg production of v-notched lobsters. 15p.

The paper by Bayer is apparently an early version of the paper by Daniel, et al., hence we will review Daniel, et al. and most comments will apply to the other.

The study consisted of 800 survey questionnaires sent to MLA members. The return rate was 21 percent. They first note that the average of the reported weight per landing is similar to that computed from the annual DMR surveys. This is presented as a demonstration of the integrity of the survey data. This comparison does not necessarily confirm the validity of the reported number of berried and v-notched females.

The first major result is that 29 percent of the trapped females is v-notched. To evaluate this result we must realize that this fraction will depend on the size range sampled and the time of year the sample is taken. There will be a larger fraction of v-notched females in the larger sizes, and there will also be relatively more v-notched lobsters later in the year after the newly berried lobsters have been either removed by the fishery or V-notched.. Thus, the fact that the study was done in October of each year after most newly molted individuals have been caught and fishermen may have moved to deeper waters after larger lobsters, could inflate this number.

A second point with regard to the results from this study is the large amount of variability in the reported data. The fraction of trapped females that were v-notched and had no eggs (the largest contributor to the 29 percent figure) varied substantially over the 3 years and 7 counties (10.9 percent to 44.9 percent). Daniel et al. found no explanation for this. It is intriguing that with one exception (Hancock county in 1984), Cumberland and Lincoln counties have ratios that are more than twice the ratios of the other counties.

In addition to the large amount of variability, there are other disconcerting aspects in these data. For example, the reported ratio of unberried females to berried females among the V-notched animals is 3 to 1. Since mature females bear eggs every other year, one would expect a ratio closer to 1 to 1.

The first major conclusion drawn from the collected data is that the fraction of females in the population is .587. This value depends on the same potential biases as the ratio of v-notched females. A second problem with this number is that the non one-to-one ratio is implicitly attributed to the recent v-notching efforts, with no attempt to compare the contribution of v-notching (to the sex ratio) to the contribution of the berried law. Protection of berried females also affects the sex ratio.

The next step was to compute the number of eggs that would be produced by each v-notched lobster and compare it to the number of eggs that would be produced by each landed lobster (i.e. not berried or v-notched). The initial problem with this comparison is that landed lobsters are not reproductive. The distribution of landed lobsters is thus not a good standard of comparison. This computation results in the proposition that v-notched lobsters produce 15 times as many eggs as the landed lobsters. This

is true because the landed lobsters are smaller and, for the most part, are not sexually mature. From the relative numbers of each they conclude that v-notched lobsters produce 6 times as many eggs each year as landed lobsters. Since this happens with only 30 percent tagged, they conclude that it is necessary to v-notch only 5 percent of the trapped lobsters for v-notching to contribute an equivalent number of eggs to landed lobsters. In addition to problems with this argument, the fraction of female lobsters in the population that are v-notched will be far less than the fraction of trapped berried lobsters being v-notched by fishermen. (i.e. The fraction v-notched in the population depends on the mortality rate, the harvest rate and other variables in addition to the v-notching rate.

Another point is that this comparison is not the appropriate one to best evaluate the effect of v-notching on the fishery. The appropriate comparison is the total number of eggs produced under v-notching versus total egg production without v-notching.

Campbell, A. 1982. Movements of tagged lobsters released off Port Maitland, Nova Scotia, 1944-1980. Can. Tech. Rpt. Fish. and Aquat. Sci. 1136:41p.

This is a report of the results of analysis of returns from lobsters tagged in an inshore fishery during 1944-68 and 1978-80. The lobsters were tagged before the fishing season and some were immature. Little long distance movement was observed, and it was along shore. Lobsters were at large only a short time. During the early years there was a substantial potential for tag loss during molts. Any existing long distance movement would have been difficult to detect in this study.

Anthony, V.C. and J.F. Caddy. 1980 Proceedings of the Canada-U.S. Workshop on Status of Assessment Science for N.W. Atlantic Lobster (Homarus americanus) Stocks, St. Andrews, N.B., Oct. 24-26, 1978). Can. Tech. Rept. Fish. Aquat. Sci. 932:186p.

From this document, we review here only the papers that have not been reviewed above.

1. Russel, H.J. The determination of growth rates for American Lobsters.

This is a review of estimates of lobster growth in recent times in the U.S., primarily by the Lobster Scientific Committee of the State-Federal Fisheries Management Program. The author first outlines their preferred approach, determining size-at-age from modes of length frequency plots, then fitting a von Bertalanffy curve to them. He states that they do not have confidence in methods that make use of actual measurements of growth (i.e. molt increment and frequency). While the length frequency data is not presented, hence can not be examined, we suspect that the mode identification procedure is ambiguous and would have greater confidence in methods that depended on measured growth.

He compares the growth curves for various locations. No attempt is

made to interpret or justify the differences in the curves.

2. Ennis, G.P. Recent and current Canadian research on growth of lobsters in the wild.

Canadian researchers use length frequency analysis too, but also make use of molt increment data and the fraction molting per unit time. They then go to a von Bertalanffy representation.

3. Anthony, V.C. Review of lobster mortality estimates in the United States.

Anthony first catalogs the various estimates of fishing or total mortality rate. In general estimated total instantaneous mortality rate is about 2. It is possibly less offshore but probably greater than 1.5. He states that Thomas' (1973) estimates of natural mortality rates range from 0.02 to 0.35 (see review above). He mentions two other estimates that are 0.26 for Massachusetts and .07 for Rhode Island.

4. Campbell, A. A review of mortality estimates of lobster populations in the Canadian Maritimes.

Campbell reviews estimates of total mortality rates which vary from 0.5 to 5.3.

5. Krouse, J. Summary of lobster, Homarus americanus, tagging studies in American waters (1898-1978)

Krouse begins with tagging studies by Bumpus, which detected some movement south or southwest. Since the 1950s several tagging studies have been conducted. Krouse reviews only the information on movement gained from these studies. Early studies detected no migration. In the late 1950s Dow detected some long migrations to the south. Krouse (1977) tagged 2900 legal lobsters in 1975. One percent traveled greater than 10 mi. south or southwest.

6. Stasko, A.B. Tagging and lobster movements in Canada.

Stasko reports little long distance movement has been detected in Canadian studies, except for seasonal movements. He notes seasonal inshore-offshore movement in Nova Scotia and Browns Bank, and that there are more berried lobsters offshore.

Additional References

Campbell, A. 1986. Implications of size and sex regulations for the lobster fishery of the Bay of Fundy and Southwestern Nova Scotia. In press in Workshop on Invertebrate Stock Assessment and Management, Nanaimo, B.C., May 7-10, 1984.

This paper examines: (1) changing the lower size limit and (2) establishing a maximum size regulation with or without berried female protection. The lower and upper size limits had been examined earlier using the same model in Campbell (1985) reviewed above. We will therefore comment only on results pertinent to the berried female issue.

Addition of berried female protection increases yield-per-recruit slightly when there is no upper limit, but decreases yield-per-recruit when there is an upper limit. Eggs-per-recruit is higher when there is berried female protection. In the discussion he notes that increasing the lower size limit by one molt increment would increase yield-per-recruit by 30 to 35 percent, but would incur a first year loss of 67 percent. Protection of berried females has little effect on yield-per-recruit, but increases eggs-per-recruit substantially.

Bannister, R.C.A. 1986. Assessment and population dynamics of commercially exploited shellfish in England and Wales. In press In the Workshop on Invertebrate Stock Assessment and Management, Nanaimo, B.C., May 7-10, 1984.

Bannister discusses recent yield-per-recruit analyses for Homarus gammarus. This species is similar to its North American congener, but the fishery has no upper limit or berried law (see review of Bennet and Edwards above). He notes that increasing the lower size limit increases both yield and eggs-per-recruit, while a berried law decreases yield-per-recruit and increases eggs-per-recruit.

Daniel, P.C., R.C. Bayer, and J.S. Krouse. 1985. Movements of large female American lobsters (Homarus americanus) tagged and released the Maine coast.

This paper reports the results of a tagging study undertaken to determine the movements of large lobsters. 2000 individuals in the size range of 89 to 136mm carapace length were tagged each fall in 1983 and 1984. The lobsters were v-notched and fishermen were asked to record tag number, location depth, date, shell condition, and whether the lobster had eggs before returning it to the water.

The authors analyze only the captures in 1984 of the 1983 releases, which were all females for some unstated reason. They compare those moving more than 37 km with those moving less than 37 km (about 23 miles). 89 percent of the returns were less than 37 km and these showed predominantly onshore-offshore seasonal movements. Of the 11 percent of the returns that showed movement greater than 37 km (29 individuals total), the average distance moved was 110 km (68 miles) and the predominant was southwest. Of these individuals, 4 were later recovered near their original release site. Although there are not enough data to draw firm conclusions, the fraction migrating long distances appeared to increase with size.

Krouse, J.S. 1981. Movement, growth, and mortality of American lobsters, Homarus americanus, tagged along the coast of Maine. NOAA Tech. Rept. NMFS SSRF-747.

This document reports the results of a tagging study conducted off the Maine coast in 1975. Approximately 3,000 lobsters were tagged in the spring. The returns were mostly local (about 1 percent were greater than 10 nm) because of the high fishing intensity and possibly the fact that not many large lobsters were tagged. Mortality rates were computed from the data on returns versus time, but these were abnormally high because the data were taken during the part of the season with highest effort and there was substantial tag loss.

Richardson, E., and J.M. Gates. 1982. A bioeconomic analysis of carapace length regulation for the American lobster fishery. Staff Paper No. 82-09. University of Rhode Island, Department of Resources Economics.

The papers by Richardson and collaborators are similar to prior work in several dimensions. First, on the biological side, the basic model utilizes the Hancock method to compute short term losses associated with carapace length increases. This is similar to the modeling effort employed in the FMC study. Similarly, on the economic side, the Wang and Kellog demand analysis is used to predict wholesale and ex-vessel price impacts of landings changes—just as was done in the FMC study. The Richardson work departs from previous studies on several fronts:

i) instead of assuming effort remains constant the Richardson work predicts how effort will respond to profitability in the long run. For example, predictions suggest that the larger long run abundance will result in about 5% more effort than in the current situation.

ii) interaction between on and off shore fisheries is explicitly accounted for, on the economic side. Although the Richardson work does not link the two fisheries biologically, the results of the economic analysis yield some potentially important conclusions. In particular, the increased long-term inshore yield reduces wholesale prices which in turn causes an exodus from the offshore fishery.

iii) The Richardson work utilizes a more sophisticated method of "counting up" all of the impacts as they occur over time. First of all, a method of estimating impacts over the entire transition period is employed—in contrast to the typical method of examining "first year" and "long term" affects. In point of fact, the most severe effects do occur during the first year and then the system rapidly approaches its long run position. However, for calculating the present value of gauge increases, it is still important not to ignore subsequent transitioning-period data. The Richardson work is the only work to summarize results on a directly comparable present value basis.

iv) The Richardson work examines the cost side of the impact picture as well as the revenue side. Data was collected on daily and yearly costs for a variety of boat sizes in Rhode Island and these were used to estimate coastwide fishing costs.

Acheson, J.M. 1985. The Maine lobster market: between market and hierarchy. Forthcoming in the Journal of Law, Economics and Organization.

The Acheson paper describes the types of arrangements which have developed between fisherman, dealers, wholesalers and retailers in the lobster marketing system. His major point is that the system which exists is a kind of hybrid between a purely market system and one where transeactions take place in a hierarchy or vertically integrated organization. There is a considerable amount of information distortion and opportunism up and down the marketing chain which might ordinarily lead to more hierarchical organizations such as co-ops. At the same time, however, the strong sense of independence among fishermen and the diversity of conditions regionally impede formation of larger vertically integrated units. What remains is a comprise structure in which loose alliances are formed between different individuals up and down the chain in order to insure supply and guarantee a fair price. These interpretations are important for the insights they provide into how fishermen and dealers might view the market impacts of carapace length changes. In addition, they have other implications for structuring the market model part of the lobster study in progress.

Wilson, J.A. 1980. Adaption to uncertainty and small numbers exchange the New England fresh fish market. Bell Journal of Economics, vol. 11, No. 2, Autumn, pp. 491-504.

This paper discusses the structure of the New England fish markets of the ex-vessel, dealer, and wholesale levels. The main concern is whether asymmetrical access to fish price information creates inefficiencies and distortions in the system. The author finds that the system of long term bilateral relationships which have developed between buyers and sellers mitigates some of the inefficiencies which would normally occur in impaired spot markets. In particular many fishermen enter into implicit contracts with buyers with whom they "trade" a steady supply for other services such as dock space, bait, loans, etc. The importance of these stable relationships is that they tend to make prices "sticky", i.e., there is not, necessarily, a rapid and immediate adjustment of prices associated with periodic shortfalls or surpluses. Instead, short term inequities are compensated for and smoothed out over a longer time between parties involved in the bilateral relationships.

Salia, S.B. and J.M. Flowers. 1965. A simulation study of sex ratios and regulation effects with the American lobster, Homarus americanus. Proceedings of the Gulf and Caribbean Fisheries Institute 18:16-78.

In this early work on management of the lobster fishery, Salia and Flowers evaluate protection of berried females and an upper size limit in terms of numbers surviving, total egg production, and sex ratio. In their model, females molt every other year and reproduce every other year. Males molt every year. The growth increment is 14 percent and the upper size limit is reached after the fourth molt (in the fishery).

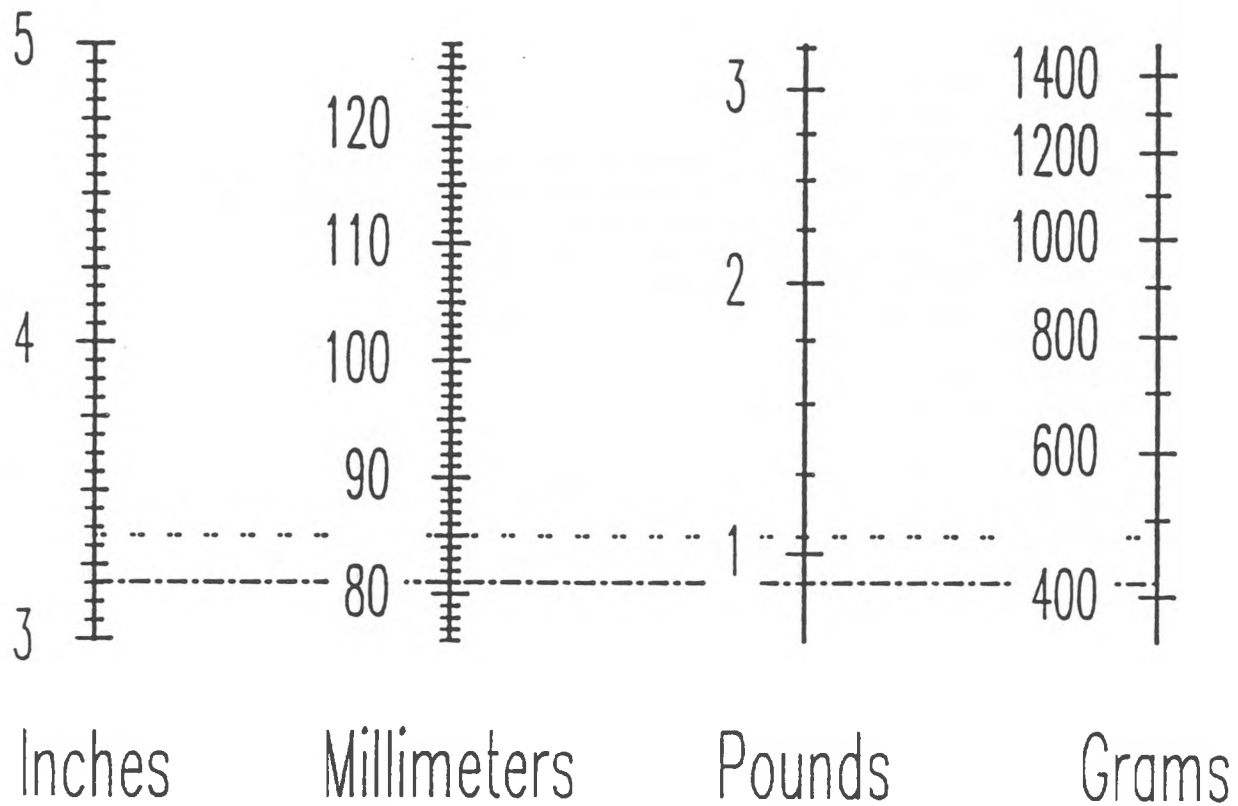
From the fact that a low percentage of females survive 4 molts, they conclude that there is no biological justification for the upper size limit. The problem with this conclusion is that they don't compare total egg production with the upper limit to total egg production without it. On the basis of the fact that berried protective doubles fecundity they recommend protecting berried females. They also plot sex ratios versus molt which are very high in the first molt in the fishery (greater than 1.5, females to males) then decline to near zero in later molts. This occurs because males are molting at twice the rate of females in their model. This probably does not occur in nature because the male molting rate declines almost as rapidly as the female (e.g. Campbell 1985).

APPENDIX 2

Figure A1. The relationships between carapace length in inches or millimeters, total weight in pounds or grams for Maine lobster. The weight length relationship used is

$$w = .001669 l^{2.8278}$$

where w is weight in grams and l is carapace length in millimeters.



APPENDIX 3. ACKNOWLEDGEMENT

The following is a list of people that we contacted in regard to this study. We thank them for their assistance.

Jay Krouse, Maine Department of Maine Resources
Mike Fogarty, National Marine Fisheries Service, Woods Hole, Mass.
Mike Sissenwine, National Marine Fisheries Service, Woods Hole, Mass.
Vaughn Anthony, National Marine Fisheries Service, Woods Hole, Mass.
Robert Bayer, University of Maine, Orono
Peter Daniel, University of Maine, Orono
James Acheson, University of Maine, Orono
James Wilson, University of Maine, Orono
William Atwood, Marketer, Spruce Head
Peter Larsen, Marketer, Port Clyde
William Bryant, Marketer, Port Clyde
Alan Campbell, Department of Fisheries and Oceans, St. Andrews, N.B.
Glen Jamieson, Department of Fisheries and Oceans, Nanaimo, B.C.
Joe Vachon, Maine Lobstermen's Association, Saco
Bob Morrell, U.S. Customs House, Portland, Me.
Stanley Huang, NMFS, Gloucester, Mass.
R. Schultz, Northeast Fisheries Center, Woods Hole, Mass.
Steve Petrovich, NMFS Market News, N.Y.
Jim Rafforty, NMFS Market News, N.Y.
Emerson Hasbrouk, NMFS Statistical Office, Riverhead, N.Y.
Dick Schween, NMFS, Office of Data & Information Management, Washington, D.C.
Jim Price, NMFS, Office of Data & Information Management, Washington, D.C.
Bob Lewis, Department of Marine Resources, Hollowell, ME
Scott Burken, Department of Marine Resources, Hollowell, ME
Jim Fair, Department of Marine Fisheries, Boston, Mass.
Bruce Estrella, Department of Marine Fisheries, Sandwich, Mass.

Lobster Wholesalers and Retailers Contacted:

Mayflower Seafood Co., Plymouth, Mass
The Lobster Pound, Manouet, Mass.
Atwood Brothers, Inc., Tenants, ME.
William Atwood Lobster Co., Spruce Head, ME
James Hook & Co., Boston, Mass.
Turner Fisheries, Boston, Mass.
Aerial Lobster, Inc., Bouton, Mass
Baystate Lobster Co., Bouton, Mass.
Lobster Locker, New Bedford, Mass.
Clark's Cove Lobster, New Bedford, Mass.
MacLeans, New Bedford, Mass.
Dave Hendrigo Seafoods, Inc., Point Judith, RI
Point Judith Fishermen's Coop, Point Judith, RI
J & L Shellfish, Naragansett, RI
Point Judith Lobster, Naragansett, RI
Champlins Seafood, Naragansett, RI

APPENDIX 4

A Survey of U.S. Lobster Fishery Management - Current Regulations and Future Prospects

Lobster fishery management regulations include primarily licensing and catch/effort reporting requirements, restrictions on the trapping gear and fishing during certain periods of the day, and prohibitions on the landing of gravid females, shucked meat, and live lobsters below a specified minimum size. Table 6 summarizes these regulations by state. Recent regulatory changes include:

(1) On January 1, 1983, New Jersey promulgated regulations (mandated by legislation) that a) prohibit the landing of lobster meat; b) regulate by size the landing of lobster parts; c) decrease the minimum size governing live lobster landings from 3 1/8" to 2 3/4"; d) require the implementation of a four year series of increasing live lobster minimum sizes (and commensurate increases in the sizes governing the landing of parts) of 2 7/8" in 1984, 3" in 1985, 3 1/8" in 1986, and 3 3/16" in 1987; and e) require escape vents in trapping gear effective in 1987;

(2) On April 1, 1984, New Hampshire promulgated regulations (mandated by legislation) which increased the minimum size from 3 1/8" to 3 3/16";

(3) On January 1, 1986, the Connecticut legislature repealed all statutes governing the landing of lobsters and simultaneously the Connecticut Department of Environmental Protection promulgated identical harvest regulations using existing regulatory authority (legislative override of DEP promulgated regulations is still possible).

To determine the extent of support within the region for lobster conservation measures, selected officials within the region were asked to comment on those lobster conservation measures considered by the Maine legislature recently. Table 7 contains the names of those contacted. A brief set of notes on of their comments is as follows.

Five inch maximum carapace length - Currently no support for 5" maximum outside Maine. Characterized as a "backwards" approach to providing additional recruitment. Opinions seem to be based on work conducted during the early 1970's (Saila and Flowers 1972, Thomas 1973) which indicates that, due to the extremely high rates of fishing mortality in lobster fisheries, an insignificant number of lobsters actually attains this size. Thus, it is often stated that no sound biological justification for this measure exists.

Hatchery program development - Only Massachusetts Lobstermen's Association (MLA) supports dedicated funding of a hatchery program. Most management officials oppose the development of hatchery capacity due to difficulties in measuring the effectiveness of stocking programs, extremely high rates of larval mortality within the environment, and cost.

Massachusetts lobster hatchery now primarily a marine research station and efforts are continuing to redirect emphasis from lobster culture to mariculture in general. Several managers note the potential role for a hatchery program in mitigating the effects of recruitment collapse.

V-notching - Massachusetts repealed a voluntary program in 1972, New Hampshire repealed a mandatory program in 1977. Currently little support for this regulation outside Maine although all make clear that Maine is justified in adopting the conservation measure. MLA fishermen are opposed to a mandatory V-notch program but will support a voluntary one. Only new Jersey management expressed the opinion that V-notching has sound biological basis, although reservations exist concerning the potential for increased mortality due to the notch. Like 5" oversize, current opinion seems to have developed out of work sponsored by the State/Federal lobster management program during the 1970's. MLA thinks this information is probably dated and feels that perhaps the potential effectiveness of the measure deserves further investigation.

Increase minimum size above 3 3/16" - Strongest support for increase in Massachusetts although Bill Lund indicates that support among management and fishermen regionally, with the exception of the Maine inshore fishermen, is generally positive. Legislation has been considered by the Massachusetts legislature for several years and Massachusetts Division of Marine Fisheries indicates it will probably draft its own version of legislation this year. Massachusetts desires coordinated effort for change but does not preclude unilateral action due to market power of wholesalers in Boston. MLA lobstermen have achieved consensus on desirability of gauge increase but are undecided about magnitude and timing of increase(s). New Jersey will achieve 3 3/16" in 1987 and management indicates fishermen not feeling adverse effects of current program of increases. New Hampshire indicates gauge increase in 1984 hurt fishermen, and that it would be difficult to develop support for another soon. Rhode Island feels some type of size increase is inevitable but will not initiate change. Many cite desirability of economic study of this measure.

Trap limits - No support for trap limits regionally although often discussed by management. Many feel it is a good idea but major problems with issues of enforcement and how to deal with trap replacement. MLA states effective limits need to acknowledge differences in fishing behavior regionally and that a high level of cooperation from fishermen would be necessary. MLA wants license limitation before trap limits so that new entrants will not inflate total trap numbers. Bill Lund sees no future for this measure in Federal waters.

Limited entry - Massachusetts has operational program to provide for the orderly expansion of the inshore fishery. They allow 100 new licenses annually from a waiting list of about 3000. Management states that transfer provisions for licenses currently preclude any attrition from the fishery, and so entry is not limited but escalates continually. Managers note that limited entry schemes are often brought up when issues of gear conflict are discussed and many full-time fishermen are beginning to view limited entry as a potential method for shrinking participation by part-time harvesters.

Others feel that the "economics of fishing" limits entry sufficiently.

Closed fishing seasons - Support for this measure variable. Massachusetts contemplating this measure as a solution to gear conflicts. Others advocate the need for a biological or economic basis for any closure, and suggest the period of molting and reproduction as appropriate. MIA notes that due to regional differences in water temperatures it is likely that closed seasons would have to vary by region, and possibly among years within the same region.

Apprenticeship program - Generally little support for this measure. Massachusetts operates something like the apprenticeship programs proposed in recent Maine legislation in conjunction with its fishery licensing program. Purchasing a new license requires minimum qualifications of 6 months full-time lobster fishing or 1 year full-time commercial fisherman. Other states note that it is common for mates and sons to enter the fishery and so an apprenticeship program is not viewed as necessary to maintain professionalism. Some view the measure as a potential way to limit entry.

Table 6 Lobster Regulations by State*

	<u>ME</u>	<u>NH</u>	<u>MA</u>	<u>RI</u>	<u>CT</u>	<u>NY</u>	<u>NJ</u>
1. <u>License Requirements</u>							
no license required							
required to fish lobster	X	X	X	X	X	X	X
required to land lobster	X	X	X	X	X		
required to deal in lobster	X	X	X	X	X		
2. <u>Legal provisions for aquaculture enterprises</u>	X	X	X	X	X	X	X
3. <u>Fishermen Classification</u>							
none							
commercial	X	X	X	X	X	X	X
non-commercial		X	X	X	X	X	
4. <u>Catch/Effort Reporting</u>							
not required							X
required annually	X	X	X		X	X	
requires daily record				X	X		
5. <u>Gear Regulations</u>							
none							X
by license class:		X	X	X	X	X	
quantity allowed		X	X			X	
type allowed	X	X	X			X	
owner identification required	X	X	X	X	X	X	
escapement opening in catching device specified	X		X	X			
6. <u>Fishing Activity Regulations</u>							
none							
by license class or method:			X	X		X	X
number of licences			X				
catch quotas						X	
area	X	X	X			X	
season	X		X				
day or time of day	X	X	X	X	X		
landing of lobster meat regulated	X	X	X	X	X	X	X
landing of lobster parts regulated	X	X	X	X	X	X	X
landing of gravid female lobsters prohibited	X	X	X	X	X	X	X
landings of v-notched female lobsters prohibited	X						
landing of lobsters regulated by size (carapace length)	X	X	X	X	X	X	X
5 inches maximum allowed	X						
3 1/16 in. minimum all'd							
3 1/8 in. minimum all'd							X
3 3/16 in. minimum all'd	X		X	X	X	X	

* adapted from American Lobster Fishery Management Plan, updated January 1986.

Table 7: Persons Contacted

Mr. Charles Thoits, Chief Inland and Marine Fisheries
New Hampshire Department of Fish and Game
603-271-3421

Mr. James Fair, Assistant Director
Massachusetts Division of Marine Fisheries
617-727-3194

Mr. John Stolgitis, Deputy Chief
Rhode Island Department of Environmental Management
401-789-3094

Mr. Eric Smith, Senior Biologist
Bureau of Fisheries, Connecticut Department of Environmental Protection
203-443-0166

Mr. Bruce Halgren, Supervising Biologist
Bureau of Marine Fisheries, New Jersey Department of Environmental Protection
609-441-3292

Professor Bull Lund, Lobster Oversight Committee
New England Fishery Management Council
203-486-4056

Mr. Roy Tate, President
Massachusetts Lobstermen's Association
617-545-6984

QUESTIONNAIRE

Does state lobster fishery management feel that a substantial reduction in future recruitment is likely?

Why or why not?

If yes, has this information been communicated to legislators or others responsible for management policy?

Have management or legislators considered adopting a regulation prohibiting the landing of large lobsters?

Why or why not?

The management or legislators considered adopting a regulation requiring that egg bearing lobsters be "notched" before release?

Why or why not? *

Have management or legislators considered funding the development of a hatchery program for restocking the inshore fishery?

Why or why not?

Have management or legislators considered raising the minimum size to larger than 3 3/16" ?

Why or why not?

Have management or legislators considered a lobster trap limit?

Why or why not?

Have management or legislators considered limiting the number of lobster licenses issued?

Why or why not?

Have management or legislators considered limiting the lobster fishing season?

Why or why not?

Have management or legislators considered requiring an apprenticeship program for lobster fishermen?

Why or why not?

